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**EVALUATION OF PORTABLE CARBON DIOXIDE ANALYZERS  
FOR USE AT 1-ATA ON U. S. NAVY SUBMARINES**

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## **TECHNICAL REVIEW AND APPROVAL**

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The experiments reported herein were conducted according to the principles set forth in the current edition of the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

This technical report has been reviewed by the NMRI scientific and public affairs staff and is approved for publication. It is releasable to the National Technical Information Service where it will be available to the general public, including foreign nations.

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13. ABSTRACT (Maximum 200 words)					
The Naval Medical Research Institute (NMRI) was tasked by the Naval Submarine Medical Research Laboratory (NSMRL) in August 1994 to evaluate portable carbon dioxide analyzers for use at 1 ATA on U.S. Navy submarines. A plan for selection and testing of candidate analyzers was developed by NMRI and approved by NSMRL prior to start of work. Candidate analyzers were chosen based on desired requirements, market search, and preliminary testing. Five candidates were selected to undergo the following testing: precision, short-term accuracy, long-term (up to 90 days) accuracy, and effect of interfering gases and ambient temperature. Based on testing results, a non-dispersive infrared instrument, CDM-1000/long, manufactured by Geotechnical Instruments, Inc., is recommended as the best candidate for use on Navy submarines.					
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## **BACKGROUND**

The Naval Medical Research Institute (NMRI) was tasked by the Naval Submarine Medical Research Laboratory (NSMRL) in August 1994 to evaluate portable carbon dioxide ( $\text{CO}_2$ ) analyzers for use on U.S. Navy submarines. These analyzers would be used at normal submarine pressures (i.e., ~ 1 ATA) to measure  $\text{CO}_2$  levels in air throughout shipboard spaces. Such analyzers would supplement the current CAMS-I, the on-board gas analyzer, which is limited to a specific number of sampling sites and not designed to measure low  $\text{CO}_2$  concentrations (e.g., < 0.2%). These instruments could also replace the  $\text{CO}_2$  detector tubes that are used on a weekly basis but are not known to be very reliable.

## **EVALUATION PLAN**

A plan for selection and testing of candidate analyzers was developed by NMRI and approved by NSMRL prior to start of work. This plan included the requirements of the desired analyzer, as well as detailed procedures for evaluating performance.

### ***Requirements***

- 1. Essential*
  - a. Measurement range: 0 to 7.5%  $\text{CO}_2$  (sub escape limit); may require more than 1 instrument to span range.
  - b. Ambient Temperature range: 20 to 40 °C.
  - c. Interferences: accuracy limits met with sample concentrations of total hydrocarbons up to 90-day limit and CO, hydrogen, and Freons up to 1 h limits.

*2. Desired but non-essential*

- a. Short-Term Repeatability (within 10 min):  $\pm 5\%$  relative over range 0.1% to 7.5% CO<sub>2</sub>.
- b. Short-Term Accuracy (within 10 min of calibration):  $\pm 10\%$  relative over range 0.1% to 7.5% CO<sub>2</sub>.
- c. Long-Term Accuracy (up to 90 days after calibration):  $\pm 25\%$  relative over range 0.1% to 7.5% CO<sub>2</sub>.
- d. Response time: less than 30 s to 95% of reading.
- e. Physical dimensions: volume less than 0.5 cubic foot.
- f. Task appropriate: rugged, corpsman friendly, low cost.

*Selection of candidate analyzers*

Candidate analyzers would be selected based on a market search, manufacturer specifications, demonstrations, and preliminary testing by NMRI.

- 1. *Market search.* The market search consisted of a review of product literature obtained from vendors, attending of analytical exhibits at meetings, and requested demonstrations by vendors.
- 2. *Preliminary testing.* Such testing was performed by NMRI at in-house demonstrations by vendors and using loaned units.
- 3. *Selection.* **Appendix A** provides detailed information regarding instruments reviewed resulting in 5 candidate analyzers being chosen for formal testing by NMRI. All use non-dispersive infrared detection as their method of analysis. The 5 analyzers are listed below:

a. Model CD-1300-P, Enmet Corp.

0 to 10% CO<sub>2</sub>

Analog readout

Zero and span adjustment

b. Model RIKEN RI-411A, RKI Instruments, Inc.

0 to 9.95% CO<sub>2</sub>

Digital readout

Zero and span adjustment

Fixed scale, X.XX (last decimal last reads in 0.05

increments)

c. Model 302 BD, NOVA Analytical Systems, Inc.

0 to 10% CO<sub>2</sub>

Digital readout

Span adjustment, no zero adjustment

Fixed scale, X.X

d. Model CDM-1000/long, Geotechnical Instruments, Inc.

0 to 7.5% CO<sub>2</sub>

Digital readout

Span adjustment, no zero adjustment

Variable scale, X.XXX for 0 to 0.999, X.XX for 1.00 to 8.00

Long = long pathlength cell

e. Model CDM-1000/short, Geotechnical Instruments, Inc.

0 to 7.5% CO<sub>2</sub>

Same specifications as CDM-1000/long

Short = short pathlength cell

To facilitate discussion, these analyzers will be referred to in this report as Enmet, RKI, Nova, GeoL, and GeoS, respectively.

***Summary of testing procedures***

One of each of the 5 candidate analyzers was tested for the following:

1. *Precision* (short-term repeatability)

Calibrated instruments were presented with the same mixture multiple times over a 10-minute period and variability noted. This was done with a range of CO<sub>2</sub> concentrations and on multiple occasions.

2. *Short-term accuracy*

Calibrated instruments were presented with a range of mixtures over 20-30 min and the difference noted between actual value and measurement. This reflected both precision and linearity of instrument and was also limited by error in the test gases. The longer test time vs. the initial 10-minute requirement was necessary as complete concentration-response curves were generated as discussed below.

3. *Long-term accuracy*

Short-term accuracy tests were repeated up to 90 days without re-calibration. This reflected short-term accuracy and long-term drift of instrument calibration (i.e., zero and gain).

#### *4. Interfering gases*

Precision and short-term accuracy tests were repeated with a range of CO<sub>2</sub> calibration mixtures containing carbon monoxide, hydrogen, Freons, and aromatic and aliphatic hydrocarbons. Interfering gas concentrations were chosen based on 1-hour submarine limits for the first 3 species and 90-day limits for the hydrocarbons, as 1-hour limits have not been established.

#### *5. Ambient temperature*

Effect of ambient temperature on analyzer measurement was examined from ~10 °C to ~35 °C.

#### *6. Field testing*

Determination of suitability for use in submarine environments and degree of "sailor friendliness" was made by field testing on 1 submarine.

#### *7. Interpretation of results*

Pass/fail criteria for analyzer performance is given under Requirements section above. Criteria for judging suitability for use by submariners and use in a submarine environment were based on Requirements and also included feedback from field testing.

## **METHODS**

All laboratory testing, except that under the section Ambient Temperature, was done at temperatures normally between 19 and 24 °C. However, during the latter part of the long-term accuracy test, laboratory temperatures occasionally ranged up to 30 °C due to air conditioning problems. Changes in barometric pressure were ignored.

### **Laboratory testing**

The following gases were used during testing:

Zero gas: CO<sub>2</sub>-free, hydrocarbon-free air.

Span gases: Four primary gravimetric standards: 0.25%, 2.5%, 5.0%, and 10% CO<sub>2</sub>, all in balance hydrocarbon-free air and certified to  $\pm$  1% relative.

Gas was delivered to the analyzers using a precision gas divider (STEC model SGD-710, Horiba Instruments, Inc., Ann Arbor, MI). The STEC device allowed blending of the 4 CO<sub>2</sub> standards with a diluent gas (hydrocarbon-free air) in 10 equal steps from 0 to 100% of the original CO<sub>2</sub> concentration. This divider has been previously shown to be linear to within the manufacturer's specification of  $\pm$  0.5% of full scale, using 5 to 100 ppm levels of a number of volatile organic compounds (1-2) and up to 25% of fixed gases (e.g., O<sub>2</sub>, CO<sub>2</sub>). In this way, accuracy of analyzers could be tested over entire calibration curves (0 to 100% of each test mixture) rather than only at the 4 concentrations of the mixtures. The only exception was for the 10% CO<sub>2</sub> gas where the maximum STEC setting used was 80% resulting in a maximum CO<sub>2</sub> concentration of 8%. The Enmet and Nova analyzers were not tested with the lowest CO<sub>2</sub> standard, 0.25%, as the first instrument's analog display did not resolve such low concentrations and the second instrument's digital display did not go below 0.1%.

Teflon tubing was used to connect the standards and diluent gases to the STEC. Wide-bore (1/4-inch inner diameter) Tygon tubing containing a tee was used to deliver gas to the inlet port of the analyzer. Gas flow was adjusted so that a slight excess flow was delivered resulting in several liters/min leaving the overflow (**Fig. 1**). In this manner, gas was sampled without pressurizing the instrument.

*1. Precision*

- a. Instrument was turned on and allowed warmup time per instrument manual.
- b. Instrument was calibrated per instructions in manual. Hydrocarbon-free gas was used as the zero gas where zero gas was required. One of the four 4 CO<sub>2</sub> standards was used as the span gas with STEC at 100% (except STEC = 80% for 10% CO<sub>2</sub> standard).
- c. One minute was waited.
- d. Zero gas was sampled and measurements taken when stabilized.
- e. Span gas was sampled and measurements taken when stabilized.
- f. Steps d-e were repeated every 2 min for a total of 5 times during which calibration controls were not touched.
- g. Steps b-f were repeated for the other 3 CO<sub>2</sub> standards.
- h. This test was done at the beginning of each short-term accuracy test (below).

*2. Short-term accuracy*

- a. Instrument was turned on and allowed warmup time per manual.
- b. Instrument was calibrated per manual using 1 of the 4 span gases and zero gas (if required).
- c. One minute was waited.
- d. STEC setting was varied from 0 to 100% of span gas and back to 0% (0 to 80% and back to 0% of span for 10% CO<sub>2</sub> standard) and measurements taken when stabilized.
- e. Steps b-d were repeated for the other 3 CO<sub>2</sub> standards.
- f. This test was run weekly for a total of 4 weeks.
- g. Minimum test concentration was 0.025% CO<sub>2</sub> (STEC=1 for 0.25% CO<sub>2</sub>).

*3. Long-term accuracy*

- a. This testing was started after all precision and short-term testing had been completed.
- b. Testing, as per short-term accuracy, was repeated weekly for a total of 13 weeks, but analyzer was calibrated only once at the start of the first week's test using 8% CO<sub>2</sub>.

*4. Interfering gases*

- a. Precision and short-term accuracy testing were repeated using each of the following 5 gravimetric standards, all prepared in hydrocarbon-free air, as the diluent gas for STEC:

- (1) ~1000 ppm CO
- (2) ~1% Hydrogen
- (3) ~3000 ppm Freon 114  
~3000 ppm Freon 12
- (4) ~10 ppm Toluene  
(~38 mg/m<sup>3</sup>)
- (5) ~50 ppm Octane  
(~230 mg/m<sup>3</sup>)

The listed concentrations are the nominal values that were certified to  $\pm 2\%$  of reported values.

- b. These gases were chosen based on the following limits from the Submarine Atmosphere Control Manual (3):

	Limits	
	<u>1 hour</u>	<u>90 day</u>
Carbon monoxide	400 ppm	
Hydrogen	1%	
Freon 12	2000 ppm	
Freon 114	2000 ppm	
Total aromatic hydrocarbons (less Benzene)	NE	10 mg/m <sup>3</sup>
Total aliphatic hydrocarbons (less methane)	NE	60 mg/m <sup>3</sup>

NE = limit has not been established.

c. As the STEC setting was varied from 0 to 100%, the resulting interfering standard concentration in the gas going to the analyzer would change from 100 to 0% of its prepared value. In this way, contaminant concentrations would bracket the actual submarine limits given above.

d. No effect by the testing setup (e.g., absorption by the tubing) on the volatile organic mixtures (Freons, octane, and toluene) was detected. This was shown by sampling gas upstream and downstream of the setup using the TVA-1000 portable toxic vapor analyzer (Foxboro Co., East Bridgewater, MA).

e. To expedite completion of our study, this test was done once during the period when long-term accuracy testing was being done.

##### 5. *Ambient temperature*

- a. All 5 instruments were turned on and allowed to warm up for 15 min.
- b. Instruments were calibrated with 8% CO<sub>2</sub> at laboratory temperature (19-21 °C).
- c. Analyzers were placed into a small animal hyperbaric chamber which was at laboratory temperature, and the door closed although not sealed to hold pressure.

d. A hull penetrator allowed gas to be delivered to the instruments in usual fashion.

Chamber temperature was regulated to  $\pm 0.5$  °C using a temperature-controlling unit (Yellow Springs Instrument Co., Yellow Springs, OH).

- e. Initial instrument readings were taken for zero air and 8% CO<sub>2</sub> at laboratory temperature by looking through the chamber viewport.
- f. The temperature controller was adjusted to maximum cooling or heating and allowed to stabilize for 2 h.

- g. Measurements were then taken again for zero air and 8% CO<sub>2</sub>.
- h. The temperature controller was then adjusted to the maximum opposite setting, and after 2 h, measurements were again taken.
- i. The controller was then set back to room temperature, and measurements were repeated after 2 h.

- j. Five complete tests were done on separate days with all analyzers tested together:
  - (1) Two tests going first to cold and then to hot
  - (2) Two tests going first to hot and then to cold
  - (3) One test remaining at laboratory temperature for 6 h as a control.

- k. Minimum and maximum chamber temperatures that could be obtained with the NMRI setup were ~10 °C and ~35 °C.

### ***Field testing***

Field testing of the recommended instrument was done by ship's personnel on the USS James K. Polk (SSN-645) during a 19-day period from 13 September to 1 October 1995. During this period, the submarine went out to sea twice. Detailed procedures are given in

## Appendix B.

This testing was designed to evaluate:

1. Stability of the instrument under actual submarine conditions.
2. Potential problems with the draft operating procedures.
3. How the CO<sub>2</sub> measurements of the analyzer compare to those from the CAMS-I.
4. Sailor "friendliness" of the instrument.

To summarize procedures, the analyzer was calibrated with 8% CO<sub>2</sub> at NMRI on 8 August 1995 prior to delivery to the submarine. During the actual field test, analyzer calibration was checked, but not recalibrated, once daily prior to use by measuring the CAMS-I calibration gas mixture (containing ~1.3% CO<sup>2</sup>) carried on all submarines. Following the calibration check, CO<sub>2</sub> measurements were taken with the analyzer once at up to 11 locations on the submarine that could also be sampled by the CAMS-I. Analyzer and CAMS-I (CO<sub>2</sub> and total pressure) measurements were taken simultaneously by using 2 people and shipboard communication. Analyzer readings were recorded when stable with the instrument positioned immediately next to the inlet of the CAMS-I sampling line.

Analyzer measurements were not corrected for the small changes in total pressure on the submarine. CAMS-I CO<sub>2</sub> and total pressure readings were displayed and recorded to the nearest 0.1 and 1 torr respectively. CAMS-I percent CO<sub>2</sub> was calculated as follows:

$$\% \text{CO}_2 = \frac{\text{CAMS-I CO}_2 \text{ (torr)}}{\text{CAMS-I pressure (torr)}} \cdot 100$$

Following the field test, the analyzer was returned to NMRI where instrument response to 0 to 8% CO<sub>2</sub> was determined, both before and after recalibration with 8% CO<sub>2</sub>, using the

STEC device.

### ***Data analysis***

Means and relative standard deviations were calculated from the precision data. Short-term and long-term accuracy data were used to calculate relative percent error:

$$\text{Relative percent error} = \frac{\text{Observed reading} - \text{Expected reading}}{\text{Expected reading}} \cdot 100$$

Expected reading was determined by multiplying the certified value of the CO<sub>2</sub> standard by the STEC setting (i.e., 0 to 100%).

As discussed above, testing with interfering gases was done during the same period as long-term testing, making re-calibration prior to testing impossible. Therefore, the gas effect was judged by calculating the difference between the measurement errors while using the interfering gases and the errors determined during the long-term test done the same week.

For Ambient Temperature data, instrument drift during cold and hot exposures was calculated relative to the initial lab temperature in the following manner:

$$\text{Drift } (\% \text{CO}_2 / ^\circ\text{C}) = \frac{\text{Reading at test temperature (cold or hot)} - \text{Initial reading}}{\text{Test temperature} - \text{Initial lab temperature}}$$

$$\text{Percent Drift } (\% / ^\circ\text{C}) = \frac{\text{Drift} \cdot 100}{\text{Initial reading}}$$

## **RESULTS AND DISCUSSION**

### ***Precision***

Results are given in **Table 1**. Some data for the lower concentration gases are missing from the table for the following reasons: a) the Enmet and Nova instruments were not tested

with the lowest concentration standard for reasons given above and b) problems arose with acquisition of some of the gases and some of the instruments at the start of this study.

With the exception of the Enmet with analog readout, relative standard deviations based on 5 measurements over 10 min was  $\leq 2\%$  for all instruments down to 2.5% CO<sub>2</sub>. No problem with zero drift was observed with any instruments.

*Conclusion:* All analyzers, except the Enmet, met the 5% precision requirement using 2 relative standard deviations as an index of precision.

#### ***Short-term accuracy***

All analyzers, with the exception of the Enmet, had a relative error of  $\leq 10\%$  for measurements from 8% down to ~1%. (**Table 2; Fig. 2**). Calibration with lower concentration standards improved measurement at lower levels. The GeoL and GeoS worked well ( $\pm 10\%$ ) down to ~0.25%, although at these levels small absolute errors translated into large relative errors. No problem with zero drift was observed with any instruments.

Representative response curves for each instrument for the 4 CO<sub>2</sub> standards are given in **Fig. 3**. As testing took place immediately after calibration, these curves would represent the "best-case" in terms of error.

*Conclusion:* The GeoL and GeoS analyzers were the best analyzers in terms of meeting the 10% accuracy requirement from 8% down to ~0.25%. The Enmet did not meet the requirement, even at the higher concentrations.

#### ***Long-term accuracy***

All analyzers, except the Enmet, completed the long-term testing over 13 weeks (**Table 2**). The Enmet was eliminated from the test after 11 weeks after repeatedly exceeding the

25% accuracy requirement. All instruments, except the Enmet, met the accuracy limit at concentrations from 8% down to ~0.5-1%. No problem with zero drift was observed with any instruments. Procedural error during Week 6 resulted in loss of data and calibration in the GeoL and GeoS. Consequently, both instruments were re-calibrated prior to Week 7's test. **Fig. 4** summarizes the data well and suggests negligible effect of re-calibration on the test (i.e., compare Weeks 6 and 7 results). The clear leader in terms of long-term accuracy is the GeoL. The GeoL met the accuracy requirement down to concentrations < 0.05%, quite a remarkable feat.

*Conclusion:* The GeoL was clearly the best analyzer in terms of long-term accuracy following a one-time initial calibration with 8% CO<sub>2</sub>.

#### ***Interfering gases***

Differences between measurement errors with and without interfering gases were generally < 10% for the 4 instruments tested. This error is similar to short-term accuracy and thus an effect due to any of the 5 gases could not be detected. The ability to detect small effects due to gas was limited by doing this testing during the long-term accuracy test period when calibration was not permitted. However, any such effects should be inconsequential in terms meeting the relatively liberal accuracy requirements. The Enmet was not tested as it had been excluded after failure during the long-term accuracy test.

*Conclusion:* All 4 analyzers appeared to be unaffected by the interfering gases.

#### ***Ambient temperature***

All instruments showed temperature drifts up to  $\pm 0.2\%$  CO<sub>2</sub>/°C, which translate to  $\pm 3\%$  of the test concentration reading (**Fig. 5**). This effect dropped to  $\pm 0.1\%$  CO<sub>2</sub>/°C and

$\pm 1\%$  of test reading if the Nova analyzer is omitted. The Enmet instrument was not tested, as it had been eliminated from the study by the time this last phase was done. Average starting, cooling, and heating temperatures were approximately 20 °C, 12 °C, and 34 °C. During the control test where ambient temperature was held constant (20.0 °C  $\pm 0.5$ ), analyzer measurements changed from starting values up to  $\pm 0.3\%$  CO<sub>2</sub> over 6 h. No problem with zero drift was observed with any instruments.

*Conclusion:* The RKI, GeoL, and GeoS responded to changes in ambient temperature similarly. The Nova was slightly more responsive to heating and cooling which would be a negative factor against its selection. Calibration of any of the first 3 instruments at normal room temperatures (18-24 °C) should result in acceptable accuracy when used at ~10 to 35 °C.

#### ***Field testing***

During the 10 days of actual testing, daily measurement of the 1.353% CO<sub>2</sub> CAMS-I calibration gas using the recommended instrument (GeoL, see below) ranged from 1.350 to 1.420% CO<sub>2</sub>. CAMS-I measurements from the various compartments of the submarine ranged from 0.27 to 1.02% CO<sub>2</sub> with total pressure within the various compartments from 747 to 791 torr. Differences between CAMS-I and GeoL measurements ((CAMS-I) - GeoL) ranged from -0.14 to 0.08% CO<sub>2</sub>. On average, CAMS-I values were 0.05% CO<sub>2</sub>, or ~9% of reading, lower than those of the GeoL.

NMRI testing following return of the instrument suggested that a shift in the calibration of the analyzer had occurred. This shift resulted in relative error lowest when measuring 1% CO<sub>2</sub> and increasing up to ~18% error as the CO<sub>2</sub> in the test gas was raised to 8%. Such performance would be expected if the instrument had been recalibrated with the

1.3% CO<sub>2</sub> CAMS-I calibration gas sometime during the field test. Ship's personnel indicate this had not occurred. Additional field testing would be needed to resolve this issue and determine if long-term accuracy as measured in the lab is a reliable measure of long-term accuracy in the field.

Ship's personnel reported no problems with the GeoL and were very enthusiastic about it.

*Conclusion:* The GeoL, the recommended analyzer, performed well during field testing although a shift in the calibration appears to have occurred during the test. Additional field testing would be needed to clarify this issue.

## SUMMARY AND RECOMMENDATIONS

All 5 candidate analyzers completed all aspects of the original test plan. It is emphasized that recommendations are based on testing results from only 1 analyzer from each of the 5 candidates.

The Enmet unit failed the precision, short-term, and long-term accuracy tests and was difficult to calibrate. It had intermittent periods in which it did not operate at all and was rejected as unreliable.

The RKI unit was not as accurate over the long term as the GeoL and GeoS, but met all of the test requirements. It is easy to calibrate and to use.

The Nova unit is considerably larger than the others, but has excellent performance characteristics. Calibrating this analyzer requires patience and a short learning curve. Once mastered, it can be easily done. The major objection is that it is bulky to handle. It passed all

of the test requirements, although its response to ambient temperature is greater than the other analyzers.

Two 0 to 7.5% Geotechnical units were tested, one with a long pathlength cell (GeoL) and one with a short pathlength cell (GeoS). Both analyzers performed flawlessly. Operation is simple and calibration is easy. The size and weight are both good. The instruments met all of the test requirements. The GeoL had better accuracy at the lowest concentrations and is recommended as the best candidate for use on U.S. Navy submarines. The GeoL performed well during field testing, although additional testing is recommended.

***Operating procedures for the recommended analyzer***

Operating procedures for the recommended analyzer, Geotechnical CDM-1000/long are given in **Appendix C**.

## REFERENCES

1. Lillo, R.S., Caldwell, J.M. Preliminary evaluation of a halogen leak detector for screening divers' breathing air. NMRI Technical Report No. 89-108, Naval Medical Research Institute, Bethesda, MD, 1989.
2. Lillo, R.S., Ruby, A., Gummin, D.D., Porter, W.R., Caldwell, J.M. Analysis of volatile contaminants in U.S. Navy fleet soda lime. NMRI Technical Report No. 95-39, Naval Medical Research Institute, Bethesda, MD, 1995.
3. U.S. Naval Sea Systems Command. Nuclear powered submarine atmosphere control manual. NAVSEA S9510-AB-ATM-010/(U). Vol. 1, rev. 2. 30 July 1992.

# Table 1 Precision Testing

R.S.D. = Relative Standard Deviation

(n = 5 in all cases)

## 8% CO<sub>2</sub>

8% CO <sub>2</sub>				5% CO <sub>2</sub>			
				Week 1 Calibrated			
				Week 2 Calibrated		Week 3 Calibrated	
				Mean	R.S.D. (%)	Mean	R.S.D. (%)
Enmet	Mean R.S.D. (%)	9.5 0	8.0 0.69	7.8 2.64	7.7 1.75	7.7 7.6 - 7.9	Enmet R.S.D. (%)
RKI	Mean R.S.D. (%)	8.100 0.00	7.970 0.56	8.070 0.83	8.060 0.28	8.050 - 8.100 8.050 - 8.100	RKI R.S.D. (%)
Nova	Mean R.S.D. (%)	8.1 1.03	8.1 1.03	8.0 0.00	8.1 0.00	-	Nova R.S.D. (%)
GeoL	Mean R.S.D. (%)	8.104 0.40	8.140 0.39	8.088 0.67	7.970 0.50	7.920 - 8.020	GeoL R.S.D. (%)
GeoS	Mean R.S.D. (%)	8.004 0.23	8.152 0.54	8.110 0.29	7.900 0.39	7.870 - 7.950	GeoS R.S.D. (%)

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## 2.5% CO<sub>2</sub>

2.5% CO <sub>2</sub>				0.25% CO <sub>2</sub>			
				Week 1 Calibrated			
				Week 2 Calibrated		Week 3 Calibrated	
				Mean	R.S.D. (%)	Mean	R.S.D. (%)
Enmet	Mean R.S.D. (%)	-	-	2.4	2.5	Enmet R.S.D. (%)	-
RKI	Mean R.S.D. (%)	2.450 0.00	2.470 1.81	2.450 1.44	2.480 1.10	RKI R.S.D. (%)	-
Nova	Mean R.S.D. (%)	-	-	2.5	2.5	Nova R.S.D. (%)	-
GeoL	Mean R.S.D. (%)	2.472 0.34	2.482 0.34	2.480 0.49	2.480 0.81	GeoL R.S.D. (%)	-
GeoS	Mean R.S.D. (%)	2.490 0.00	2.482 0.18	2.482 0.72	2.486 0.22	GeoS R.S.D. (%)	-

**Table 2A Enmet Short-term and Long-term Testing**

**Relative Percent Error**

		Short Term Test												Long Term Test																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
Stec	Expected	Week 1				Week 2				Week 3				Week 4				Week 5				Week 6				Week 7				Week 8				Week 9				Week 10				Week 11				Week 12				Week 13																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
01/10/95	01/18/95	01/27/95	02/03/95	02/10/95	02/15/95	02/24/95	03/02/95	03/08/95	03/16/95	03/20/95	03/30/95	04/05/95	04/12/95	04/19/95	04/26/95	04/20/95	04/27/95	05/03/95	05/10/95	05/17/95	05/24/95	06/07/95	06/14/95	06/21/95	07/05/95	07/12/95	07/19/95	07/26/95	08/02/95	08/09/95	08/16/95	08/23/95	08/30/95	09/06/95	09/13/95	09/20/95	09/27/95	10/04/95	10/11/95	10/18/95	10/25/95	11/01/95	11/08/95	11/15/95	11/22/95	11/29/95	12/06/95	12/13/95	12/20/95	12/27/95	01/03/96	01/10/96	01/17/96	01/24/96	01/31/96	02/07/96	02/14/96	02/21/96	02/28/96	03/04/96	03/11/96	03/18/96	03/25/96	04/01/96	04/08/96	04/15/96	04/22/96	04/29/96	05/06/96	05/13/96	05/20/96	05/27/96	06/03/96	06/10/96	06/17/96	06/24/96	07/01/96	07/08/96	07/15/96	07/22/96	07/29/96	08/05/96	08/12/96	08/19/96	08/26/96	09/02/96	09/09/96	09/16/96	09/23/96	09/30/96	10/07/96	10/14/96	10/21/96	10/28/96	11/04/96	11/11/96	11/18/96	11/25/96	12/02/96	12/09/96	12/16/96	12/23/96	12/30/96	01/06/97	01/13/97	01/20/97	01/27/97	02/03/97	02/10/97	02/17/97	02/24/97	03/01/97	03/08/97	03/15/97	03/22/97	03/29/97	04/05/97	04/12/97	04/19/97	04/26/97	04/20/97	04/27/97	05/03/97	05/10/97	05/17/97	05/24/97	06/07/97	06/14/97	06/21/97	07/05/97	07/12/97	07/19/97	07/26/97	08/02/97	08/09/97	08/16/97	08/23/97	08/30/97	09/06/97	09/13/97	09/20/97	09/27/97	10/04/97	10/11/97	10/18/97	10/25/97	11/01/97	11/08/97	11/15/97	11/22/97	11/29/97	12/06/97	12/13/97	12/20/97	12/27/97	01/03/98	01/10/98	01/17/98	01/24/98	01/31/98	02/07/98	02/14/98	02/21/98	02/28/98	03/04/98	03/11/98	03/18/98	03/25/98	04/01/98	04/08/98	04/15/98	04/22/98	04/29/98	05/06/98	05/13/98	05/20/98	05/27/98	06/03/98	06/10/98	06/17/98	06/24/98	07/01/98	07/08/98	07/15/98	07/22/98	07/29/98	08/05/98	08/12/98	08/19/98	08/26/98	09/02/98	09/09/98	09/16/98	09/23/98	09/30/98	10/07/98	10/14/98	10/21/98	10/28/98	11/04/98	11/11/98	11/18/98	11/25/98	12/02/98	12/09/98	12/16/98	12/23/98	12/30/98	01/06/99	01/13/99	01/20/99	01/27/99	02/03/99	02/10/99	02/17/99	02/24/99	03/01/99	03/08/99	03/15/99	03/22/99	03/29/99	04/05/99	04/12/99	04/19/99	04/26/99	04/20/99	04/27/99	05/03/99	05/10/99	05/17/99	05/24/99	06/07/99	06/14/99	06/21/99	07/05/99	07/12/99	07/19/99	07/26/99	08/02/99	08/09/99	08/16/99	08/23/99	08/30/99	09/06/99	09/13/99	09/20/99	09/27/99	10/04/99	10/11/99	10/18/99	10/25/99	11/01/99	11/08/99	11/15/99	11/22/99	11/29/99	12/06/99	12/13/99	12/20/99	12/27/99	01/03/00	01/10/00	01/17/00	01/24/00	01/31/00	02/07/00	02/14/00	02/21/00	02/28/00	03/04/00	03/11/00	03/18/00	03/25/00	04/01/00	04/08/00	04/15/00	04/22/00	04/29/00	05/06/00	05/13/00	05/20/00	05/27/00	06/03/00	06/10/00	06/17/00	06/24/00	07/01/00	07/08/00	07/15/00	07/22/00	07/29/00	08/05/00	08/12/00	08/19/00	08/26/00	09/02/00	09/09/00	09/16/00	09/23/00	09/30/00	10/07/00	10/14/00	10/21/00	10/28/00	11/04/00	11/11/00	11/18/00	11/25/00	12/02/00	12/09/00	12/16/00	12/23/00	12/30/00	01/06/01	01/13/01	01/20/01	01/27/01	02/03/01	02/10/01	02/17/01	02/24/01	03/01/01	03/08/01	03/15/01	03/22/01	03/29/01	04/05/01	04/12/01	04/19/01	04/26/01	04/20/01	04/27/01	05/03/01	05/10/01	05/17/01	05/24/01	06/07/01	06/14/01	06/21/01	07/05/01	07/12/01	07/19/01	07/26/01	08/02/01	08/09/01	08/16/01	08/23/01	08/30/01	09/06/01	09/13/01	09/20/01	09/27/01	10/04/01	10/11/01	10/18/01	10/25/01	11/01/01	11/08/01	11/15/01	11/22/01	11/29/01	12/06/01	12/13/01	12/20/01	12/27/01	01/03/02	01/10/02	01/17/02	01/24/02	01/31/02	02/07/02	02/14/02	02/21/02	02/28/02	03/04/02	03/11/02	03/18/02	03/25/02	04/01/02	04/08/02	04/15/02	04/22/02	04/29/02	05/06/02	05/13/02	05/20/02	05/27/02	06/03/02	06/10/02	06/17/02	06/24/02	07/01/02	07/08/02	07/15/02	07/22/02	07/29/02	08/05/02	08/12/02	08/19/02	08/26/02	09/02/02	09/09/02	09/16/02	09/23/02	09/30/02	10/07/02	10/14/02	10/21/02	10/28/02	11/04/02	11/11/02	11/18/02	11/25/02	12/02/02	12/09/02	12/16/02	12/23/02	12/30/02	01/06/03	01/13/03	01/20/03	01/27/03	02/03/03	02/10/03	02/17/03	02/24/03	03/01/03	03/08/03	03/15/03	03/22/03	03/29/03	04/05/03	04/12/03	04/19/03	04/26/03	04/20/03	04/27/03	05/03/03	05/10/03	05/17/03	05/24/03	06/07/03	06/14/03	06/21/03	07/05/03	07/12/03	07/19/03	07/26/03	08/02/03	08/09/03	08/16/03	08/23/03	08/30/03	09/06/03	09/13/03	09/20/03	09/27/03	10/04/03	10/11/03	10/18/03	10/25/03	11/01/03	11/08/03	11/15/03	11/22/03	11/29/03	12/06/03	12/13/03	12/20/03	12/27/03	01/03/04	01/10/04	01/17/04	01/24/04	01/31/04	02/07/04	02/14/04	02/21/04	02/28/04	03/04/04	03/11/04	03/18/04	03/25/04	04/01/04	04/08/04	04/15/04	04/22/04	04/29/04	05/06/04	05/13/04	05/20/04	05/27/04	06/03/04	06/10/04	06/17/04	06/24/04	07/01/04	07/08/04	07/15/04	07/22/04	07/29/04	08/05/04	08/12/04	08/19/04	08/26/04	09/02/04	09/09/04	09/16/04	09/23/04	09/30/04	10/07/04	10/14/04	10/21/04	10/28/04	11/04/04	11/11/04	11/18/04	11/25/04	12/02/04	12/09/04	12/16/04	12/23/04	12/30/04	01/06/05	01/13/05	01/20/05	01/27/05	02/03/05	02/10/05	02/17/05	02/24/05	03/01/05	03/08/05	03/15/05	03/22/05	03/29/05	04/05/05	04/12/05	04/19/05	04/26/05	04/20/05	04/27/05	05/03/05	05/10/05	05/17/05	05/24/05	06/07/05	06/14/05	06/21/05	07/05/05	07/12/05	07/19/05	07/26/05	08/02/05	08/09/05	08/16/05	08/23/05	08/30/05	09/06/05	09/13/05	09/20/05	09/27/05	10/04/05	10/11/05	10/18/05	10/25/05	11/01/05	11/08/05	11/15/05	11/22/05	11/29/05	12/06/05	12/13/05	12/20/05	12/27/05	01/03/06	01/10/06	01/17/06	01/24/06	01/31/06	02/07/06	02/14/06	02/21/06	02/28/06	03/04/06	03/11/06	03/18/06	03/25/06	04/01/06	04/08/06	04/15/06	04/22/06	04/29/06	05/06/06	05/13/06	05/20/06	05/27/06	06/03/06	06/10/06	06/17/06	06/24/06	07/01/06	07/08/06	07/15/06	07/22/06	07/29/06	08/05/06	08/12/06	08/19/06	08/26/06	09/02/06	09/09/06	09/16/06	09/23/06	09/30/06	10/07/06	10/14/06	10/21/06	10/28/06	11/04/06	11/11/06	11/18/06	11/25/06	12/02/06	12/09/06	12/16/06	12/23/06	12/30/06	01/06/07	01/13/07	01/20/07	01/27/07	02/03/07	02/10/07	02/17/07	02/24/07	03/01/07	03/08/07	03/15/07	03/22/07	03/29/07	04/05/07	04/12/07	04/19/07	04/26/07	04/20/07	04/27/07	05/03/07	05/10/07	05/17/07	05/24/07	06/07/07	06/14/07	06/21/07	07/05/07	07/12/07	07/19/07	07/26/07	08/02/07	08/09/07	08/16/07	08/23/07	08/30/07	09/06/07	09/13/07	09/20/07	09/27/07	10/04/07	10/11/07	10/18/07	10/25/07	11/01/07	11/08/07	11/15/07	11/22/07	11/29/07	12/06/07	12/13/07	12/20/07	12/27/07	01/03/08	01/10/08	01/17/08	01/24/08	01/31/08	02/07/08	02/14/08	02/21/08	02/28/08	03/04/08	03/11/08	03/18/08	03/25/08	04/01/08	04/08/08	04/15/08	04/22/08	04/29/08	05/06/08	05/13/08	05/20/08	05/27/08	06/03/08	06/10/08	06/17/08	06/24/08	07/01/08	07/08/08	07/15/08	07/22/08	07/29/08	08/05/08	08/12/08	08/19/08	08/26/08	09/02/08	09/09/08	09/16/08	09/23/08	09/30/08	10/07/08	10/14/08	10/21/08	10/28/08	11/04/08	11/11/08	11/18/08	11/25/08	12/02/08	12/09/08	12/16/08	12/23/08	12/30/08	01/06/09	01/13/09	01/20/09	01/27/09	02/03/09	02/10/09	02/17/09	02/24/09	03/01/09	03/08/09	03/15/09	03/22/09	03/29/09	04/05/09	04/12/09	04/19/09	04/26/09	04/20/09	04/27/09	05/03/09	05/10/09	05/17/09	05/24/09	06/07/09	06/14/09	06/21/09	07/05/09	07/12/09	07/19/09	07/26/09	08/02/09	08/09/09	08/16/09	08/23/09	08/30/09	09/06/09	09/13/09	09/20/09	09/27/09	10/04/09	10/11/09	10/18/09	10/25/09	11/01/09	11/08/09	11/15/09	11/22/09	11/29/09	12/06/09	12/13/09	12/20/09	12/27/09	01/03/10	01/10/10	01/17/10	01/24/10	01/31/10	02/07/10	02/14/10	02/21/10	02/28/10	03/04/10	03/11/10	03/18/10	03/25/10	04/01/10	04/08/10	04/15/10	04/22/10	04/29/10	05/06/10	05/13/10	05/20/10	05/27/10	06/03/10	06/10/10	06/17/10	06/24/10	07/01/10	07/08/10	07/15/10	07/22/10	07/29/10	08/05/10	08/12/10	08/19/10	08/26/10	09/02/10	09/09/10	09/16/10	09/23/10	09/30/10	10/07/10	10/14/10	10/21/10	10/28/10	11/04/10	11/11/10	11/18/10	11/25/10	12/02/10	12/09/10	12/16/10	12/23/10	12/30/10	01/06/11	01/13/11	01/20/11	01/27/11	02/03/11	02/10/11	02/17/11	02/24/11	03/01/11	03/08/11	03/15/11	03/22/

**Table 2A** (cont.)  
Enmet

### Relative Percent Error

**Table 2B R<sub>KI</sub> Short-term and Long-term Testing**

### Relative Percent Error

5.04% CO<sub>2</sub>

**Note:** Bold Values Exceed Test Requirements

**Table 2B (cont.)**  
**RKI**

**Relative Percent Error**

2.48% CO2			Long Term Test																																	
Stec	Expected	02/22/95	03/08/95	03/15/95	03/22/95	03/29/95	04/06/95	04/13/95	04/20/95	04/27/95	05/04/95	05/11/95	05/18/95	05/25/95	06/01/95	06/08/95	06/15/95	06/22/95	06/29/95	07/06/95	07/13/95	07/20/95	07/27/95	08/03/95	08/10/95	08/17/95	08/24/95	09/01/95	09/08/95	09/15/95	09/22/95	09/29/95				
0	0.00	-41	11	15	41	41	41	41	41	41	61	41	61	41	61	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51					
10	0.025	8	1	8	-1	-1	-9	6	6	6	16	6	16	9	1	9	17	21	21	26	26	34	34	41	41	41	41	41	41	41	41	41				
20	0.050	1	1	1	-3	-11	1	1	1	1	8	1	8	1	8	14	21	20	20	20	24	24	24	24	24	24	24	24	24	24	24	24				
30	0.075	-1	-1	-3	-13	1	1	1	1	4	7	1	9	12	1	9	12	21	21	20	20	20	20	20	20	20	20	20	20	20	20	20	20			
40	0.100	1	1	-3	-10	1	3	3	3	3	9	1	9	11	1	9	12	19	19	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16		
50	0.125	-1	-4	-4	-8	3	3	3	3	3	9	1	9	11	1	9	12	19	19	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16		
60	0.150	-3	-3	-5	-11	1	1	1	1	4	7	1	9	12	1	9	13	16	16	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15		
70	0.175	-2	-2	-5	-11	1	1	1	1	4	7	1	9	12	1	9	13	16	16	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15		
80	0.200	-4	-4	-9	1	3	3	3	3	3	9	1	9	11	1	9	12	19	19	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
90	0.225	-4	-1	-3	-7	1	3	3	3	3	9	1	9	11	1	9	12	19	19	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
100	0.250	-3	-1	-4	-10	1	3	3	3	3	9	1	9	11	1	9	12	19	19	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
110	0.275	-1	-1	-4	-12	1	1	1	1	4	7	1	9	11	1	9	12	19	19	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
120	0.300	-1	-1	-6	-16	1	1	1	1	4	7	1	9	11	1	9	12	19	19	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
130	0.325	-1	-1	-6	-19	1	1	1	1	4	7	1	9	11	1	9	12	19	19	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	
140	0.350	-1	-1	-9	-24	1	1	6	6	6	11	6	11	6	11	16	21	21	21	21	26	26	26	26	26	26	26	26	26	26	26	26	26	26		
150	0.375	-1	-6	-1	-25	8	8	8	8	8	11	8	11	8	11	16	21	21	21	21	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
160	0.400	1	1	11	-29	11	11	11	11	11	21	11	21	11	21	31	31	31	31	31	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
170	0.425	1	21	-100	-100	21	-100	-100	-100	-100	-100	21	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100			
180	0.450	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

0.26% CO2			Long Term Test																															
Stec	Expected	02/22/95	03/08/95	03/15/95	03/22/95	03/29/95	04/06/95	04/13/95	04/20/95	04/27/95	05/04/95	05/11/95	05/18/95	05/25/95	06/01/95	06/08/95	06/15/95	06/22/95	06/29/95	07/06/95	07/13/95	07/20/95	07/27/95	08/03/95	08/10/95	08/17/95	08/24/95	09/01/95	09/08/95	09/15/95	09/22/95	09/29/95		
0	0.00	-41	92	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100	-100		
10	0.025	-4	26	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	
20	0.050	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	
30	0.075	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	
40	0.100	4	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
50	0.125	15	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54
60	0.150	28	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	
70	0.175	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
80	0.200	-4	20	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
90	0.225	7	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
100	0.250	-4	15	35	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54
110	0.275	7	28	-15	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
120	0.300	4	20	44	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68	68
130	0.325	10	37	37	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92
140	0.350	-4	28	28	28	2																												

**Table 2C** Nova Short-term and Long-term Testing

### Relative Percent Error

Note: Bold Values Exceed Test Requirements

**Table 2C (cont.)**  
Nova

**Relative Percent Error**

2.48% CO2		Long Term Test																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
Stec	Expected	Short Term Test				Week 1				Week 2				Week 3				Week 4				Week 5				Week 6				Week 7				Week 8				Week 9				Week 10				Week 11				Week 12				Week 13																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
01/18/95	01/27/95	02/03/95	02/24/95	02/16/95	02/29/95	03/15/95	03/30/95	03/20/95	03/25/95	03/30/95	04/06/95	04/13/95	04/20/95	04/27/95	05/04/95	05/11/95	05/18/95	05/25/95	06/01/95	06/08/95	06/15/95	06/22/95	06/29/95	07/06/95	07/13/95	07/20/95	07/27/95	08/03/95	08/10/95	08/17/95	08/24/95	08/31/95	09/07/95	09/14/95	09/21/95	09/28/95	10/05/95	10/12/95	10/19/95	10/26/95	11/02/95	11/09/95	11/16/95	11/23/95	11/30/95	12/07/95	12/14/95	12/21/95	12/28/95	01/04/96	01/11/96	01/18/96	01/25/96	02/01/96	02/08/96	02/15/96	02/22/96	02/29/96	03/05/96	03/12/96	03/19/96	03/26/96	04/02/96	04/09/96	04/16/96	04/23/96	04/30/96	05/07/96	05/14/96	05/21/96	05/28/96	06/04/96	06/11/96	06/18/96	06/25/96	07/02/96	07/09/96	07/16/96	07/23/96	07/30/96	08/06/96	08/13/96	08/20/96	08/27/96	09/03/96	09/10/96	09/17/96	09/24/96	09/31/96	10/08/96	10/15/96	10/22/96	10/29/96	11/05/96	11/12/96	11/19/96	11/26/96	12/03/96	12/10/96	12/17/96	12/24/96	12/31/96	01/07/97	01/14/97	01/21/97	01/28/97	02/04/97	02/11/97	02/18/97	02/25/97	03/01/97	03/08/97	03/15/97	03/22/97	03/29/97	04/05/97	04/12/97	04/19/97	04/26/97	05/03/97	05/10/97	05/17/97	05/24/97	06/01/97	06/08/97	06/15/97	06/22/97	06/29/97	07/06/97	07/13/97	07/20/97	07/27/97	08/03/97	08/10/97	08/17/97	08/24/97	08/31/97	09/07/97	09/14/97	09/21/97	09/28/97	10/05/97	10/12/97	10/19/97	10/26/97	11/02/97	11/09/97	11/16/97	11/23/97	11/30/97	12/07/97	12/14/97	12/21/97	12/28/97	01/04/98	01/11/98	01/18/98	01/25/98	02/01/98	02/08/98	02/15/98	02/22/98	02/29/98	03/05/98	03/12/98	03/19/98	03/26/98	04/02/98	04/09/98	04/16/98	04/23/98	04/30/98	05/07/98	05/14/98	05/21/98	05/28/98	06/04/98	06/11/98	06/18/98	06/25/98	07/02/98	07/09/98	07/16/98	07/23/98	07/30/98	08/06/98	08/13/98	08/20/98	08/27/98	09/03/98	09/10/98	09/17/98	09/24/98	09/31/98	10/08/98	10/15/98	10/22/98	10/29/98	11/05/98	11/12/98	11/19/98	11/26/98	12/03/98	12/10/98	12/17/98	12/24/98	12/31/98	01/07/99	01/14/99	01/21/99	01/28/99	02/04/99	02/11/99	02/18/99	02/25/99	03/01/99	03/08/99	03/15/99	03/22/99	03/29/99	04/05/99	04/12/99	04/19/99	04/26/99	05/03/99	05/10/99	05/17/99	05/24/99	06/01/99	06/08/99	06/15/99	06/22/99	06/29/99	07/06/99	07/13/99	07/20/99	07/27/99	08/03/99	08/10/99	08/17/99	08/24/99	08/31/99	09/07/99	09/14/99	09/21/99	09/28/99	10/05/99	10/12/99	10/19/99	10/26/99	11/02/99	11/09/99	11/16/99	11/23/99	11/30/99	12/07/99	12/14/99	12/21/99	12/28/99	01/04/00	01/11/00	01/18/00	01/25/00	02/01/00	02/08/00	02/15/00	02/22/00	02/29/00	03/05/00	03/12/00	03/19/00	03/26/00	04/02/00	04/09/00	04/16/00	04/23/00	04/30/00	05/07/00	05/14/00	05/21/00	05/28/00	06/04/00	06/11/00	06/18/00	06/25/00	07/02/00	07/09/00	07/16/00	07/23/00	07/30/00	08/06/00	08/13/00	08/20/00	08/27/00	09/03/00	09/10/00	09/17/00	09/24/00	09/31/00	10/08/00	10/15/00	10/22/00	10/29/00	11/05/00	11/12/00	11/19/00	11/26/00	12/03/00	12/10/00	12/17/00	12/24/00	12/31/00	01/07/01	01/14/01	01/21/01	01/28/01	02/04/01	02/11/01	02/18/01	02/25/01	03/01/01	03/08/01	03/15/01	03/22/01	03/29/01	04/05/01	04/12/01	04/19/01	04/26/01	05/03/01	05/10/01	05/17/01	05/24/01	06/01/01	06/08/01	06/15/01	06/22/01	06/29/01	07/06/01	07/13/01	07/20/01	07/27/01	08/03/01	08/10/01	08/17/01	08/24/01	08/31/01	09/07/01	09/14/01	09/21/01	09/28/01	10/05/01	10/12/01	10/19/01	10/26/01	11/02/01	11/09/01	11/16/01	11/23/01	11/30/01	12/07/01	12/14/01	12/21/01	12/28/01	01/04/02	01/11/02	01/18/02	01/25/02	02/01/02	02/08/02	02/15/02	02/22/02	02/29/02	03/05/02	03/12/02	03/19/02	03/26/02	04/02/02	04/09/02	04/16/02	04/23/02	04/30/02	05/07/02	05/14/02	05/21/02	05/28/02	06/04/02	06/11/02	06/18/02	06/25/02	07/02/02	07/09/02	07/16/02	07/23/02	07/30/02	08/06/02	08/13/02	08/20/02	08/27/02	09/03/02	09/10/02	09/17/02	09/24/02	09/31/02	10/08/02	10/15/02	10/22/02	10/29/02	11/05/02	11/12/02	11/19/02	11/26/02	12/03/02	12/10/02	12/17/02	12/24/02	12/31/02	01/07/03	01/14/03	01/21/03	01/28/03	02/04/03	02/11/03	02/18/03	02/25/03	03/01/03	03/08/03	03/15/03	03/22/03	03/29/03	04/05/03	04/12/03	04/19/03	04/26/03	05/03/03	05/10/03	05/17/03	05/24/03	06/01/03	06/08/03	06/15/03	06/22/03	06/29/03	07/06/03	07/13/03	07/20/03	07/27/03	08/03/03	08/10/03	08/17/03	08/24/03	08/31/03	09/07/03	09/14/03	09/21/03	09/28/03	10/05/03	10/12/03	10/19/03	10/26/03	11/02/03	11/09/03	11/16/03	11/23/03	11/30/03	12/07/03	12/14/03	12/21/03	12/28/03	01/04/04	01/11/04	01/18/04	01/25/04	02/01/04	02/08/04	02/15/04	02/22/04	02/29/04	03/05/04	03/12/04	03/19/04	03/26/04	04/02/04	04/09/04	04/16/04	04/23/04	04/30/04	05/07/04	05/14/04	05/21/04	05/28/04	06/04/04	06/11/04	06/18/04	06/25/04	07/02/04	07/09/04	07/16/04	07/23/04	07/30/04	08/06/04	08/13/04	08/20/04	08/27/04	09/03/04	09/10/04	09/17/04	09/24/04	09/31/04	10/08/04	10/15/04	10/22/04	10/29/04	11/05/04	11/12/04	11/19/04	11/26/04	12/03/04	12/10/04	12/17/04	12/24/04	12/31/04	01/07/05	01/14/05	01/21/05	01/28/05	02/04/05	02/11/05	02/18/05	02/25/05	03/01/05	03/08/05	03/15/05	03/22/05	03/29/05	04/05/05	04/12/05	04/19/05	04/26/05	05/03/05	05/10/05	05/17/05	05/24/05	06/01/05	06/08/05	06/15/05	06/22/05	06/29/05	07/06/05	07/13/05	07/20/05	07/27/05	08/03/05	08/10/05	08/17/05	08/24/05	08/31/05	09/07/05	09/14/05	09/21/05	09/28/05	10/05/05	10/12/05	10/19/05	10/26/05	11/02/05	11/09/05	11/16/05	11/23/05	11/30/05	12/07/05	12/14/05	12/21/05	12/28/05	01/04/06	01/11/06	01/18/06	01/25/06	02/01/06	02/08/06	02/15/06	02/22/06	02/29/06	03/05/06	03/12/06	03/19/06	03/26/06	04/02/06	04/09/06	04/16/06	04/23/06	04/30/06	05/07/06	05/14/06	05/21/06	05/28/06	06/04/06	06/11/06	06/18/06	06/25/06	07/02/06	07/09/06	07/16/06	07/23/06	07/30/06	08/06/06	08/13/06	08/20/06	08/27/06	09/03/06	09/10/06	09/17/06	09/24/06	09/31/06	10/08/06	10/15/06	10/22/06	10/29/06	11/05/06	11/12/06	11/19/06	11/26/06	12/03/06	12/10/06	12/17/06	12/24/06	12/31/06	01/07/07	01/14/07	01/21/07	01/28/07	02/04/07	02/11/07	02/18/07	02/25/07	03/01/07	03/08/07	03/15/07	03/22/07	03/29/07	04/05/07	04/12/07	04/19/07	04/26/07	05/03/07	05/10/07	05/17/07	05/24/07	06/01/07	06/08/07	06/15/07	06/22/07	06/29/07	07/06/07	07/13/07	07/20/07	07/27/07	08/03/07	08/10/07	08/17/07	08/24/07	08/31/07	09/07/07	09/14/07	09/21/07	09/28/07	10/05/07	10/12/07	10/19/07	10/26/07	11/02/07	11/09/07	11/16/07	11/23/07	11/30/07	12/07/07	12/14/07	12/21/07	12/28/07	01/04/08	01/11/08	01/18/08	01/25/08	02/01/08	02/08/08	02/15/08	02/22/08	02/29/08	03/05/08	03/12/08	03/19/08	03/26/08	04/02/08	04/09/08	04/16/08	04/23/08	04/30/08	05/07/08	05/14/08	05/21/08	05/28/08	06/04/08	06/11/08	06/18/08	06/25/08	07/02/08	07/09/08	07/16/08	07/23/08	07/30/08	08/06/08	08/13/08	08/20/08	08/27/08	09/03/08	09/10/08	09/17/08	09/24/08	09/31/08	10/08/08	10/15/08	10/22/08	10/29/08	11/05/08	11/12/08	11/19/08	11/26/08	12/03/08	12/10/08	12/17/08	12/24/08	12/31/08	01/07/09	01/14/09	01/21/09	01/28/09	02/04/09	02/11/09	02/18/09	02/25/09	03/01/09	03/08/09	03/15/09	03/22/09	03/29/09	04/05/09	04/12/09	04/19/09	04/26/09	05/03/09	05/10/09	05/17/09	05/24/09	06/01/09	06/08/09	06/15/09	06/22/09	06/29/09	07/06/09	07/13/09	07/20/09	07/27/09	08/03/09	08/10/09	08/17/09	08/24/09	08/31/09	09/07/09	09/14/09	09/21/09	09/28/09	10/05/09	10/12/09	10/19/09	10/26/09	11/02/09	11/09/09	11/16/09	11/23/09	11/30/09	12/07/09	12/14/09	12/21/09	12/28/09	01/04/10	01/11/10	01/18/10	01/25/10	02/01/10	02/08/10	02/15/10	02/22/10	02/29/10	03/05/10	03/12/10	03/19/10	03/26/10	04/02/10	04/09/10	04/16/10	04/23/10	04/30/10	05/07/10	05/14/10	05/21/10	05/28/10	06/04/10	06/11/10	06/18/10	06/25/10	07/02/10	07/09/10	07/16/10	07/23/10	07/30/10	08/06/10	08/13/10	08/20/10	08/27/10	09/03/10	09/10/10	09/17/10	09/24/10	09/31/10	10/08/10	10/15/10	10/22/10	10/29/10	11/05/10	11/12/10	11/19/10	11/26/10	12/03/10	12/10/10	12/17/10	12/24/10	12/31/10	01/07/11	01/14/11	01/21/11	01/28/11	02/04/11	02/11/11	02/18/11	02/25/11	03/01/11	03/08/11	03/15/11	03/22/

**Table 2D** GeOL Short-term and Long-term Testing

### Relative Percent Error

**Note:** Bold Values Exceed Test Requirements

**Table 2D (cont.)**  
**GeoL**

**Relative Percent Error**

2.48% CO2			Short Term Test						Long Term Test									
Stec	Expected	Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
0	0.00	02/10/95 Calibrated	02/16/95 Calibrated	02/22/95 Calibrated	03/08/95 Calibrated	03/15/95 Calibrated	03/20/95 Calibrated	03/30/95 Calibrated	04/05/95 Calibrated	04/13/95 Calibrated	04/20/95 Calibrated	04/28/95 Calibrated	05/04/95 Calibrated	05/11/95 Calibrated	05/18/95 Calibrated	05/24/95 Calibrated	05/31/95 Calibrated	
10	0.3	-2	3	-6	-4	-11	-9	-7	-9	-13	-8	-9	-5	-6	-6	-4	-2	-6
20	0.5	-1	-1	-3	-2	-7	-5	-4	-5	-6	-4	-4	-1	-3	-3	-2	-2	-2
30	0.8	-2	-2	-4	-2	-6	-5	-4	-5	-7	-3	-3	-1	-1	-6	0	1	-2
40	1.0	1	1	0	0	-4	-2	-1	-2	-3	1	1	1	0	0	1	2	0
50	1.3	0	0	-2	0	-2	0	-2	0	-2	0	0	2	2	3	4	2	0
60	1.5	1	1	-3	1	-3	-1	-3	-1	-3	-1	-1	0	1	0	2	2	0
70	1.8	0	0	-2	0	-3	-1	-1	-1	-1	0	0	1	1	1	2	2	0
80	2.0	0	0	0	0	-4	-2	-2	-2	-2	-1	0	0	1	1	1	2	0
90	2.3	1	1	0	0	-5	-1	-1	-1	-1	1	1	0	0	1	2	2	1
100	2.5	1	1	1	1	-3	-2	-2	-2	-2	-2	0	0	0	0	2	2	0
90	2.3	1	1	-1	0	-2	-1	-1	-1	-1	1	1	1	0	0	3	3	0
80	2.0	1	-1	-2	1	-3	-2	-2	-2	0	1	1	0	1	1	2	2	0
70	1.8	0	1	-2	0	-3	-1	-1	-1	0	0	1	1	1	1	2	2	2
60	1.5	-2	-1	-3	-1	-3	-3	-3	-3	0	-2	1	0	1	1	2	2	0
50	1.3	1	1	-4	0	-4	-2	1	-2	-2	-2	0	0	0	0	2	4	0
40	1.0	2	-1	-5	1	-4	-3	-2	-3	-3	-2	0	0	1	1	1	0	0
30	0.8	-4	-4	-8	-4	-7	-6	-5	-6	-7	-4	-5	-3	-3	-1	1	-3	-3
20	0.50	-4	-3	-9	-4	-9	-6	-5	-6	-7	-8	-5	-4	-3	-4	-2	1	2
10	0.25	-7	-6	-22	-8	-13	-9	-9	-11	-14	-10	-9	-6	-7	-8	-7	-2	-6
0	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

0.26% CO2			Short Term Test						Long Term Test									
Stec	Expected	Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
0	0.000	02/10/95	02/16/95	02/22/95	03/08/95	03/15/95	03/20/95	03/30/95	04/05/95	04/13/95	04/20/95	04/28/95	05/04/95	05/11/95	05/18/95	05/24/95	05/31/95	
10	0.025	-54	-65	-69	-85	-85	-25	-29	-27	-25	-19	-22	-29	-58	-50	-46	-35	-58
20	0.050	-19	-13	-10	-13	-13	-22	-21	-19	-18	-18	-20	-14	-19	-17	-13	-9	-19
30	0.075	-12	-12	-14	-14	-14	-20	-20	-19	-19	-18	-20	-12	-15	-14	-12	-10	-13
40	0.100	-18	-18	-22	-22	-22	-22	-22	-22	-21	-21	-22	-17	-17	-16	-15	-14	-17
50	0.125	-18	-21	-21	-23	-23	-26	-26	-26	-25	-25	-26	-23	-23	-21	-20	-19	-19
60	0.150	-8	-12	-17	-17	-17	-20	-18	-16	-16	-16	-18	-10	-11	-12	-8	-7	-11
70	0.175	-6	-6	-9	-9	-9	-15	-15	-15	-15	-13	-13	-8	-7	-6	-4	-4	-8
80	0.200	-4	-4	-8	-8	-8	-12	-12	-11	-10	-10	-10	-5	-6	-7	-4	-2	-7
90	0.225	-7	-5	-10	-13	-14	-14	-13	-12	-12	-11	-12	-9	-9	-7	-6	-6	-9
100	0.250	-13	-10	-18	-20	-24	-24	-24	-24	-24	-24	-24	-17	-17	-17	-17	-17	-19
90	0.225	-23	-23	-26	-26	-26	-26	-26	-26	-26	-26	-26	-23	-23	-21	-21	-21	-23
80	0.200	-21	-20	-22	-22	-22	-22	-22	-22	-22	-22	-22	-21	-21	-20	-19	-19	-20
70	0.175	-18	-16	-16	-16	-16	-16	-16	-16	-16	-16	-16	-17	-17	-17	-17	-17	-17
60	0.150	-16	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14	-15	-15	-15	-15	-15	-15
50	0.125	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17
40	0.100	-19	-19	-29	-29	-29	-29	-29	-29	-29	-29	-29	-21	-21	-21	-21	-21	-21
30	0.075	-23	-23	-50	-50	-50	-55	-55	-55	-55	-55	-55	-54	-54	-54	-54	-54	-54
20	0.050	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	0.025	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
0	0.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

\* User Error - Data and calibration loss. Recalibrated prior to week 7

**Table 2E** GeoS Short-term and Long-term Testing

### Relative Percent Error

Note: Bold Values Exceed Test Requirements

**Table 2E** (cont.)  
GeoS

### Relative Percent Error

0.26% CO<sub>2</sub>

## \* User Error - Data and calibration loss. Recalibrated prior to week 7

## **FIGURE LEGENDS**

### ***Fig. 1.***

Testing Setup. Setup showing how test gases were delivered to the analyzers via STEC device during testing.

### ***Fig. 2a-e.***

Short-term accuracy. Relative error for measurements from 1 to 8% CO<sub>2</sub> immediately after instrument calibration using 8% CO<sub>2</sub>. Calibration and testing done weekly for 4 consecutive weeks.

### ***Fig. 3a-e.***

Response Curves. Analyzer response curves for 4 gas standards: 0.25, 2.5, 5, and 10% CO<sub>2</sub>. Data from one week's short-term accuracy test. Relative error plotted vs. CO<sub>2</sub> concentration. Analyzer calibrated with 1 of the 4 standards. STEC gas divider then used to deliver 0 to 100 to 0% of the standard concentration. For the 8% standard, STEC was varied only from 0 to 80 to 0%, resulting in a maximum concentration of 8%.

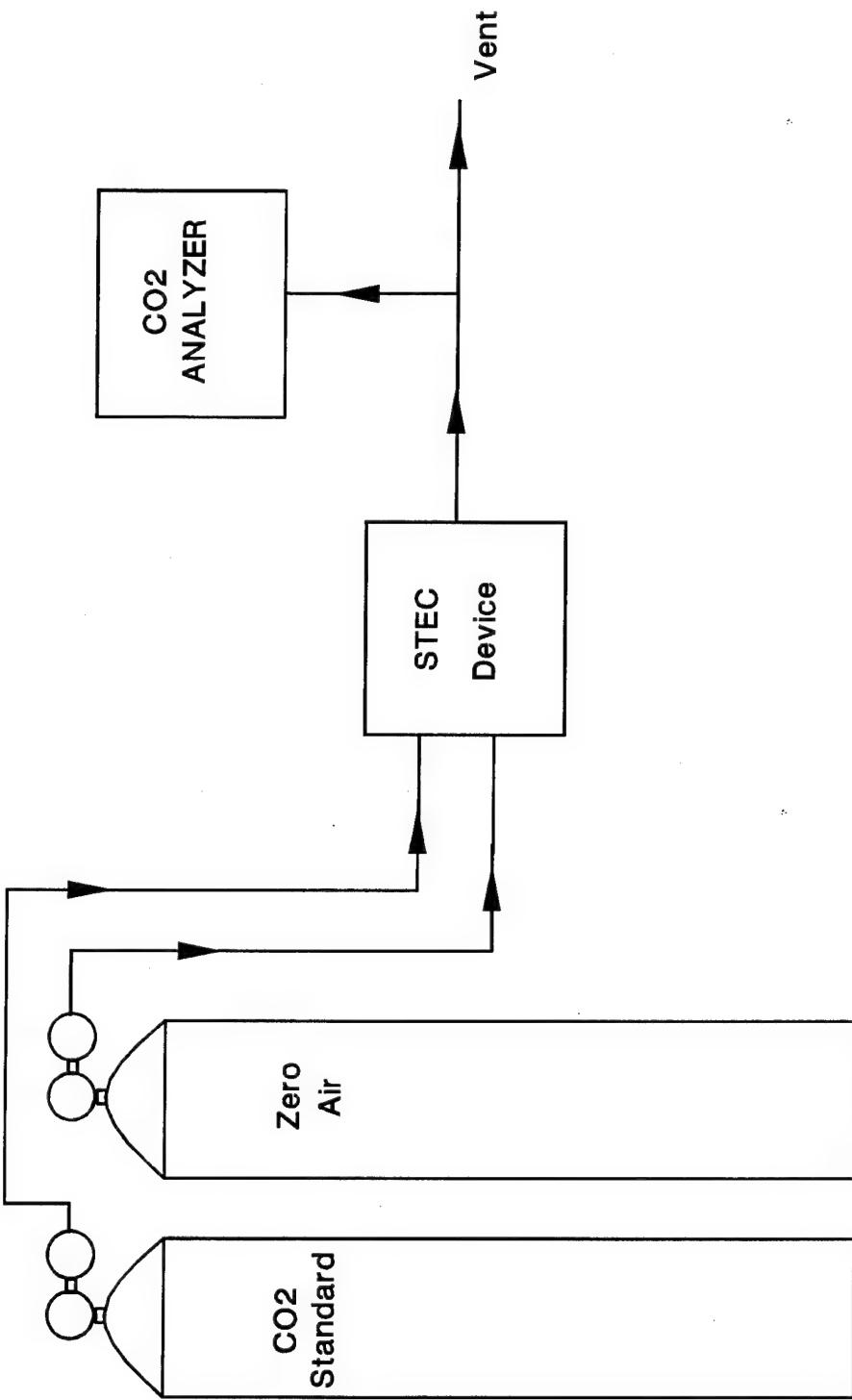
### ***Fig. 4a-e.***

Long-term accuracy. Relative error for measurements from 0.25% to 8% over 13 weeks after a one-time calibration with 8% CO<sub>2</sub> at the beginning of the test.

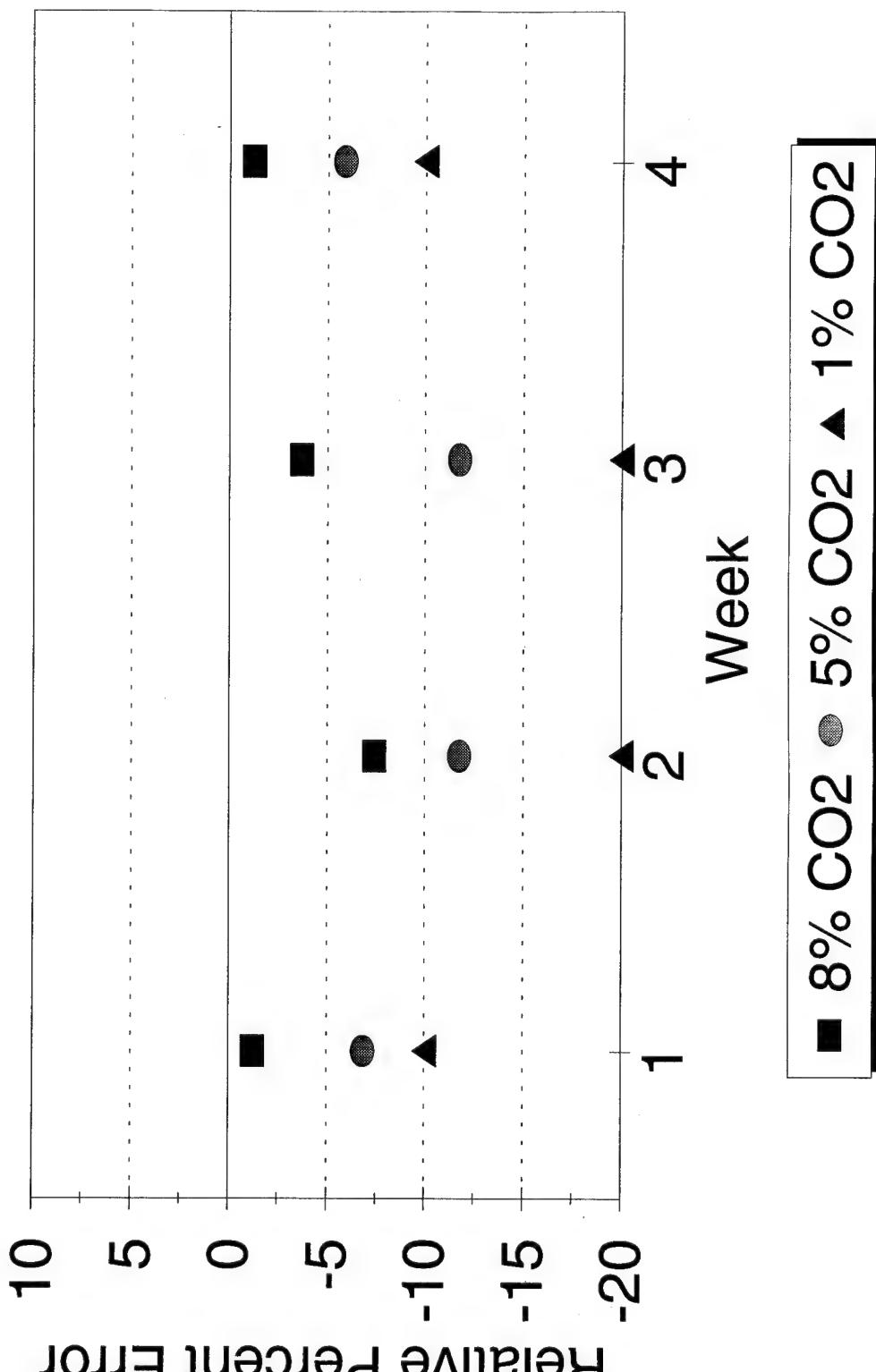
**Fig. 5a-b.**

Ambient temperature. Effect of ambient temperature change on instrument measurement of 8% after calibration with the same. Instruments were tested first at ambient temperature (~20 °C), then 2 h after being cooled (~12 °C) or heated (~34 °C). Each instrument underwent 2 sequences of ambient, then cooling, then heating, and another 2 sequences of ambient, then heating, then cooling. Drift defines the change in instrument reading for each degree C.

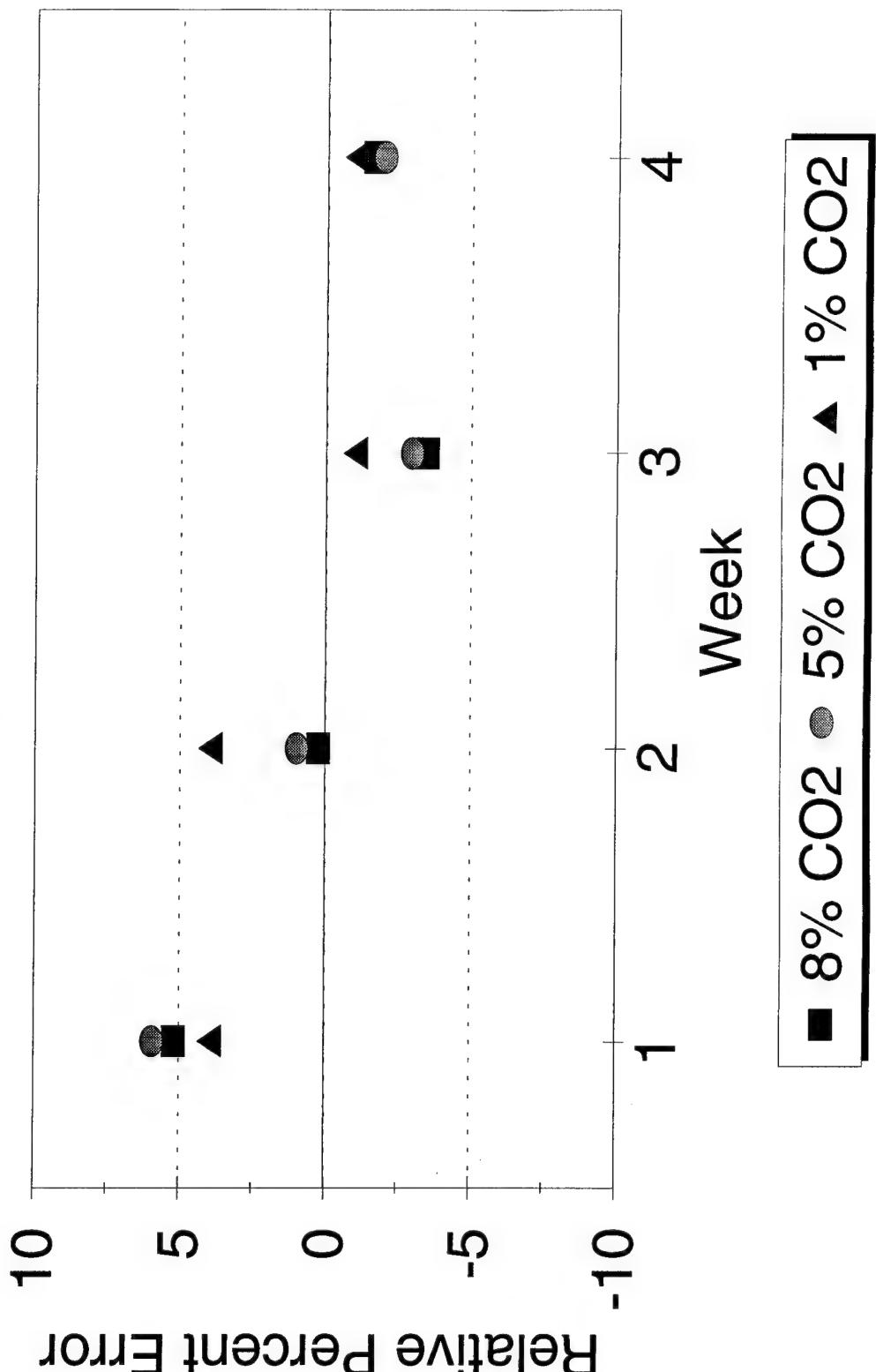
# Figure 1 Testing setup



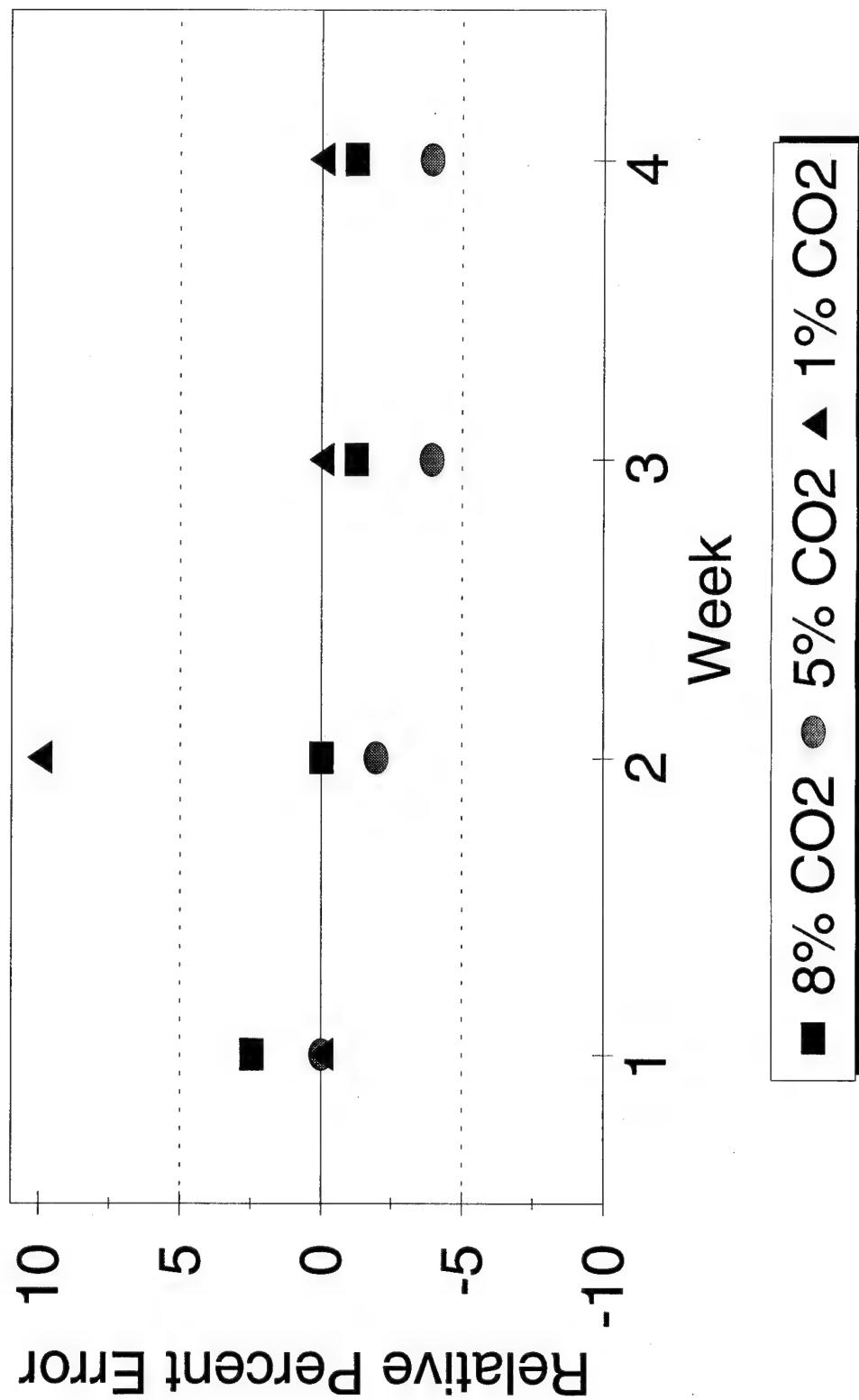
**Figure 2A**  
**Enmet Short-term Test**



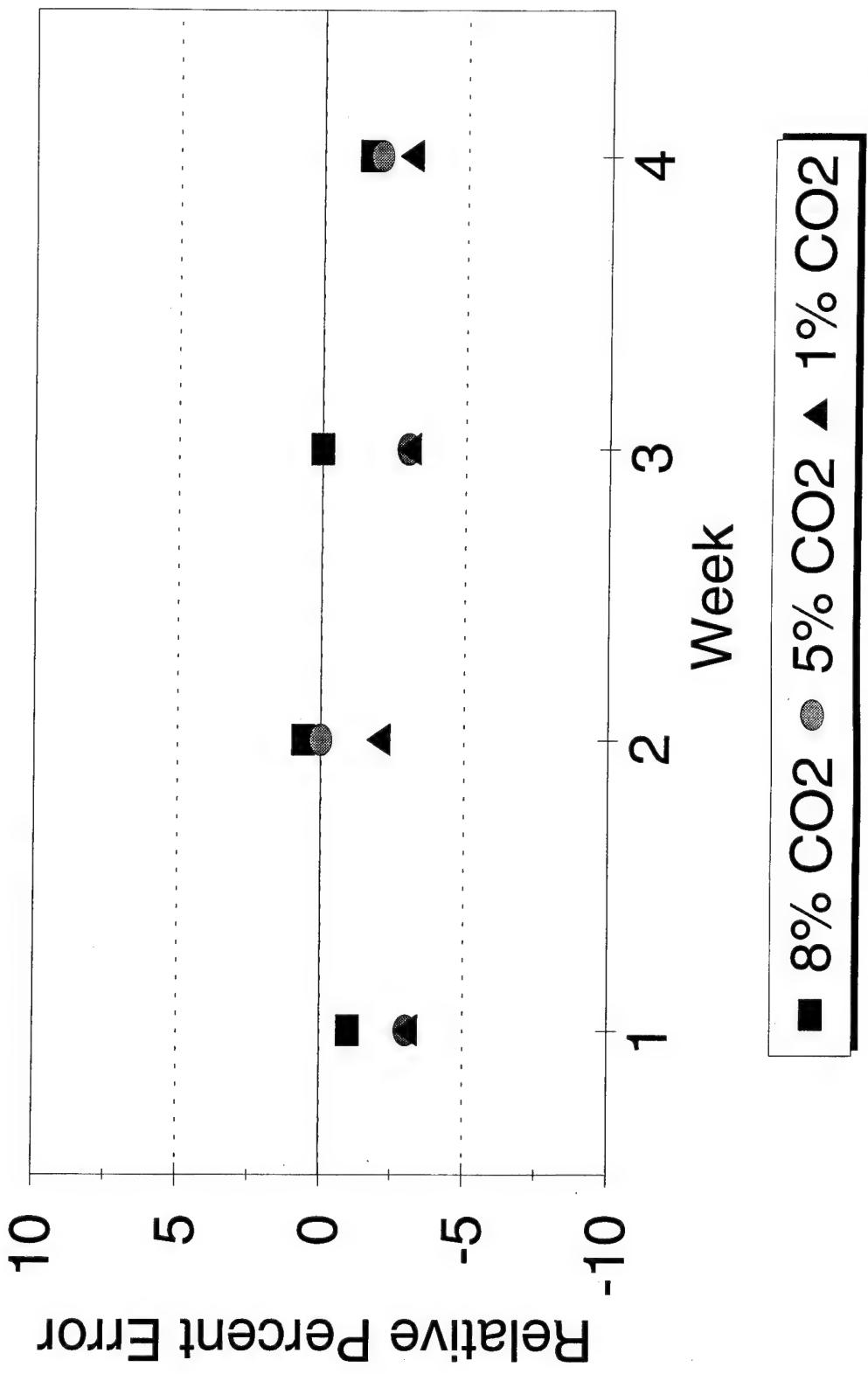
**Figure 2B**  
**RKI Short-term Test**



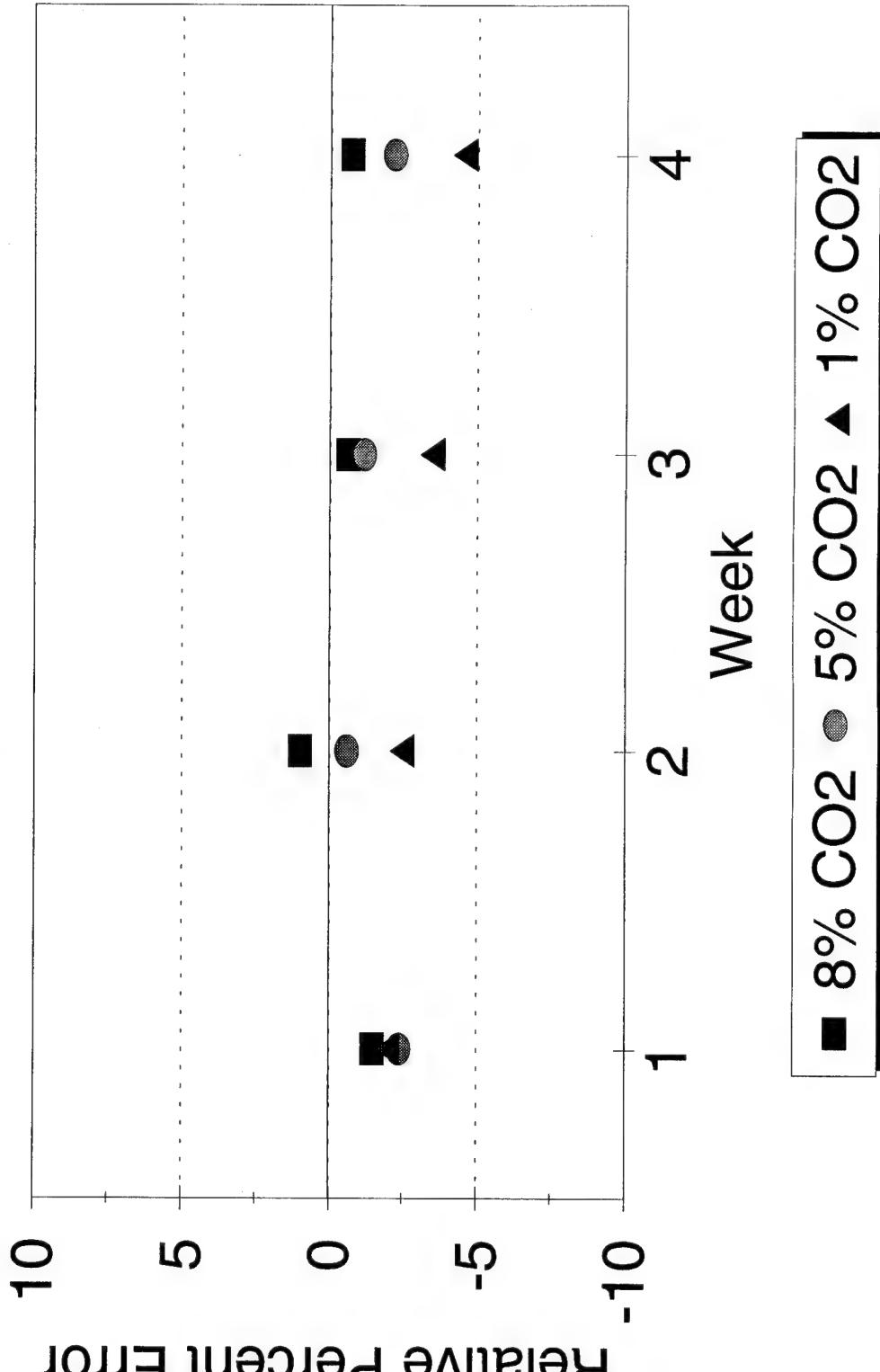
**Figure 2C**  
**Nova Short-term Test**



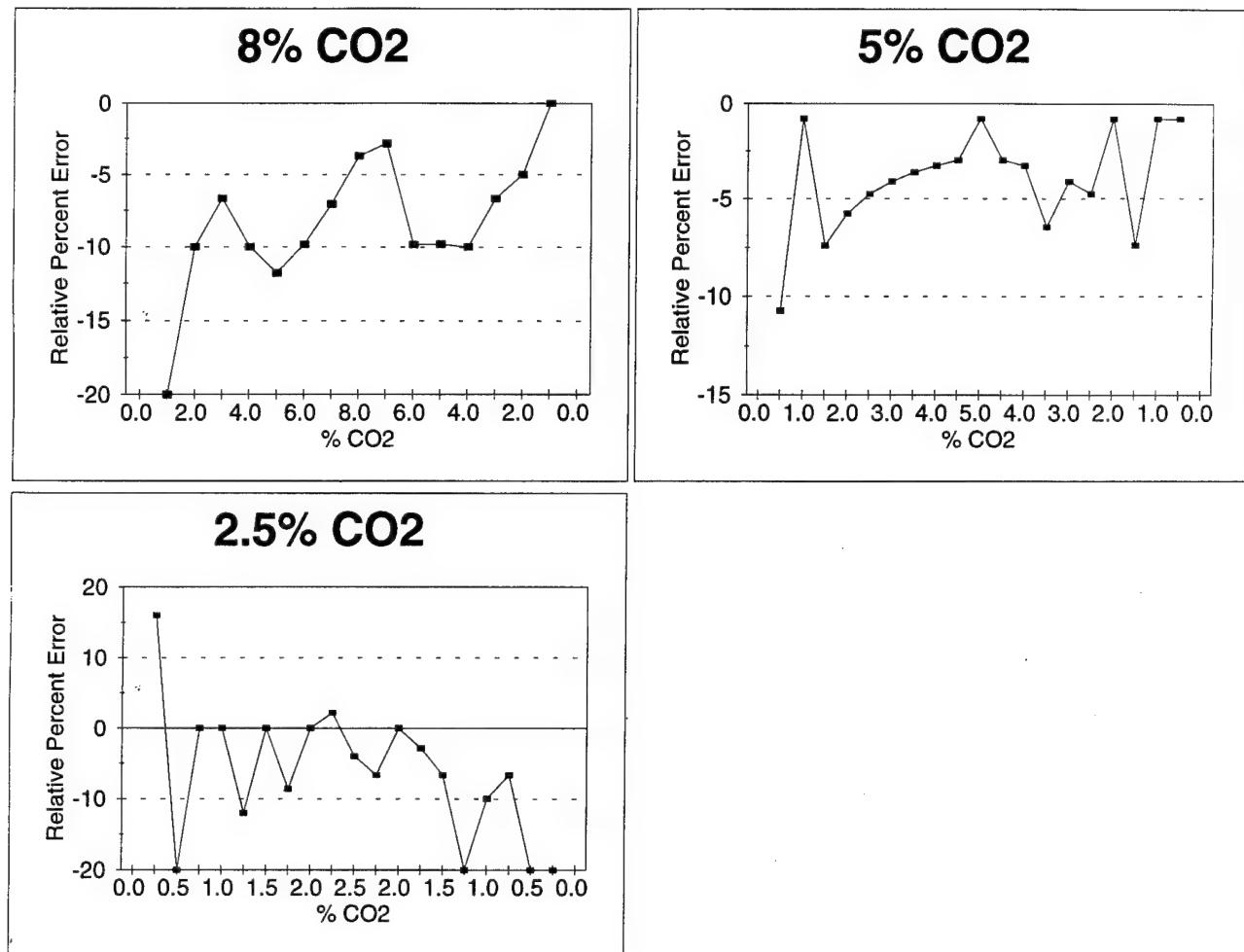
## Figure 2D GeOL Short-term Test



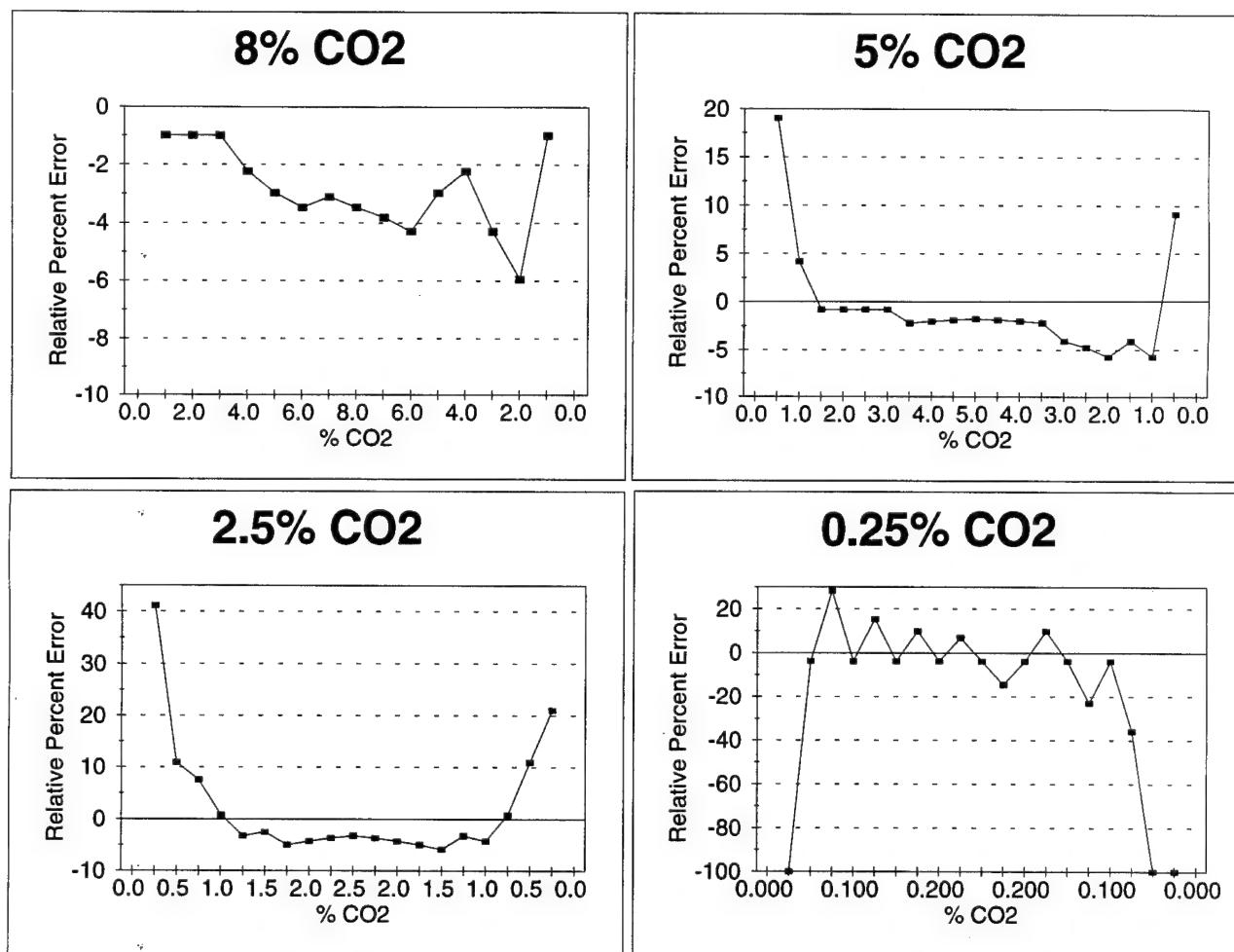
**Figure 2E**  
**GeoS Short-term Test**



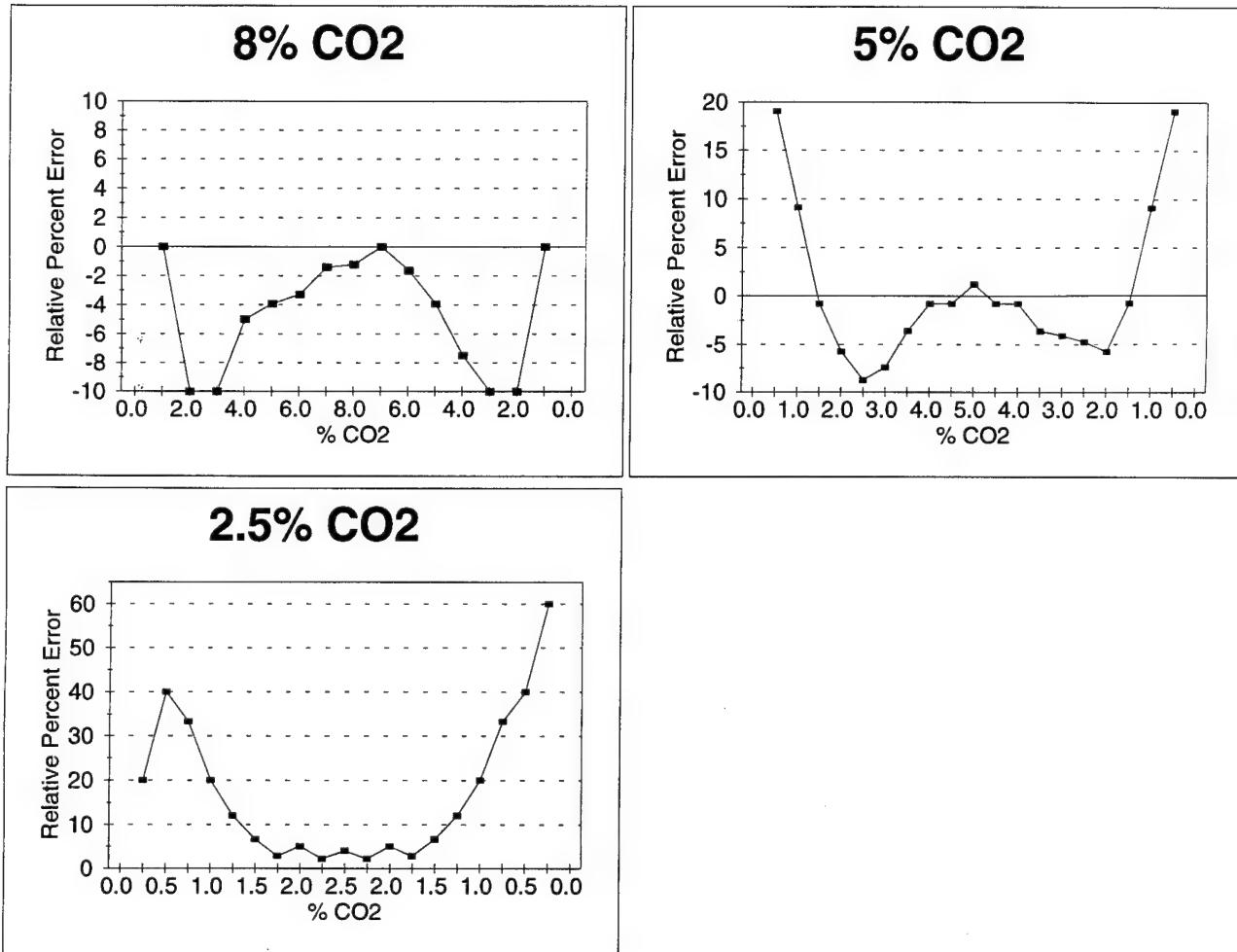
# Figure 3A Enmet Response Curves



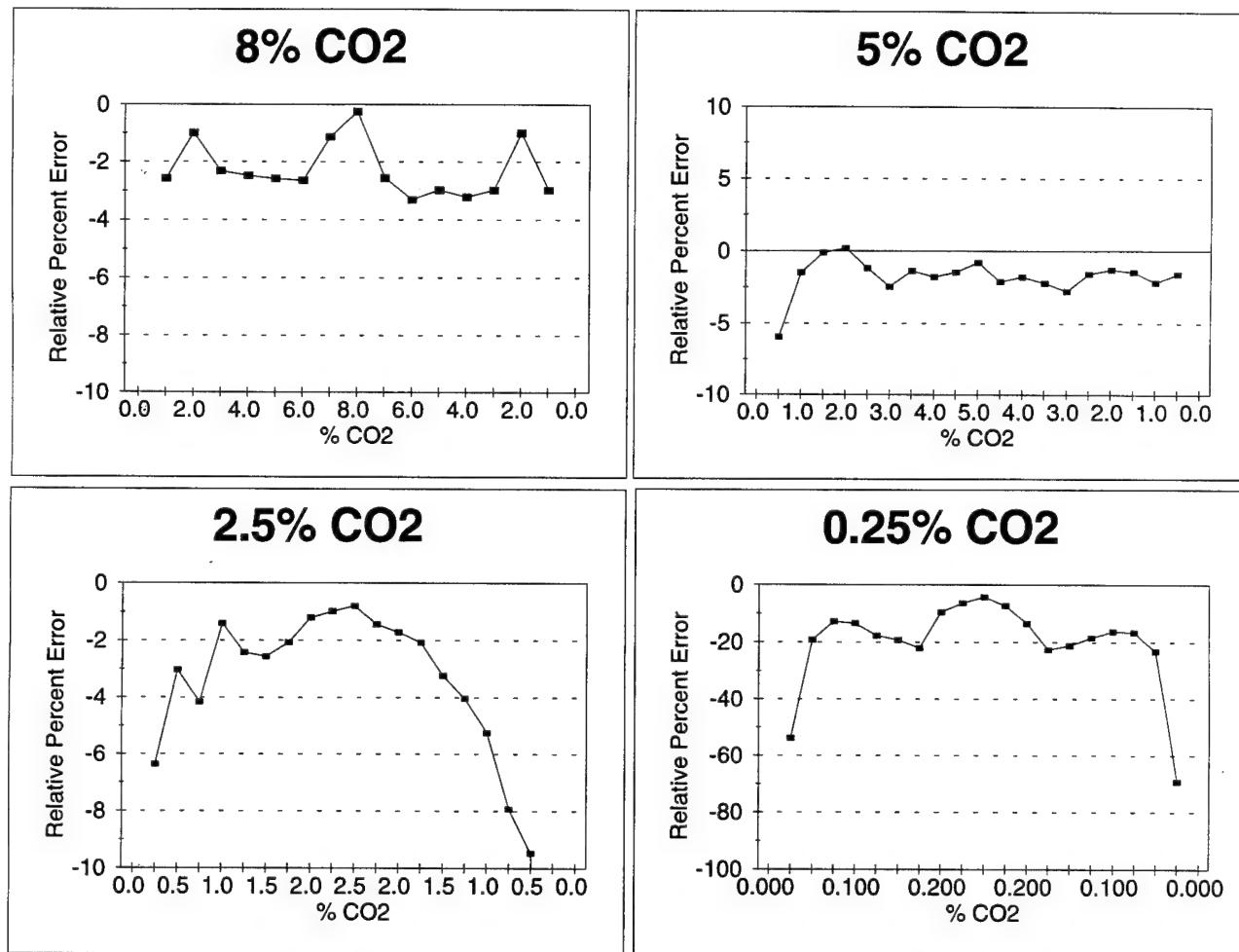
# Figure 3B RKI Response Curves



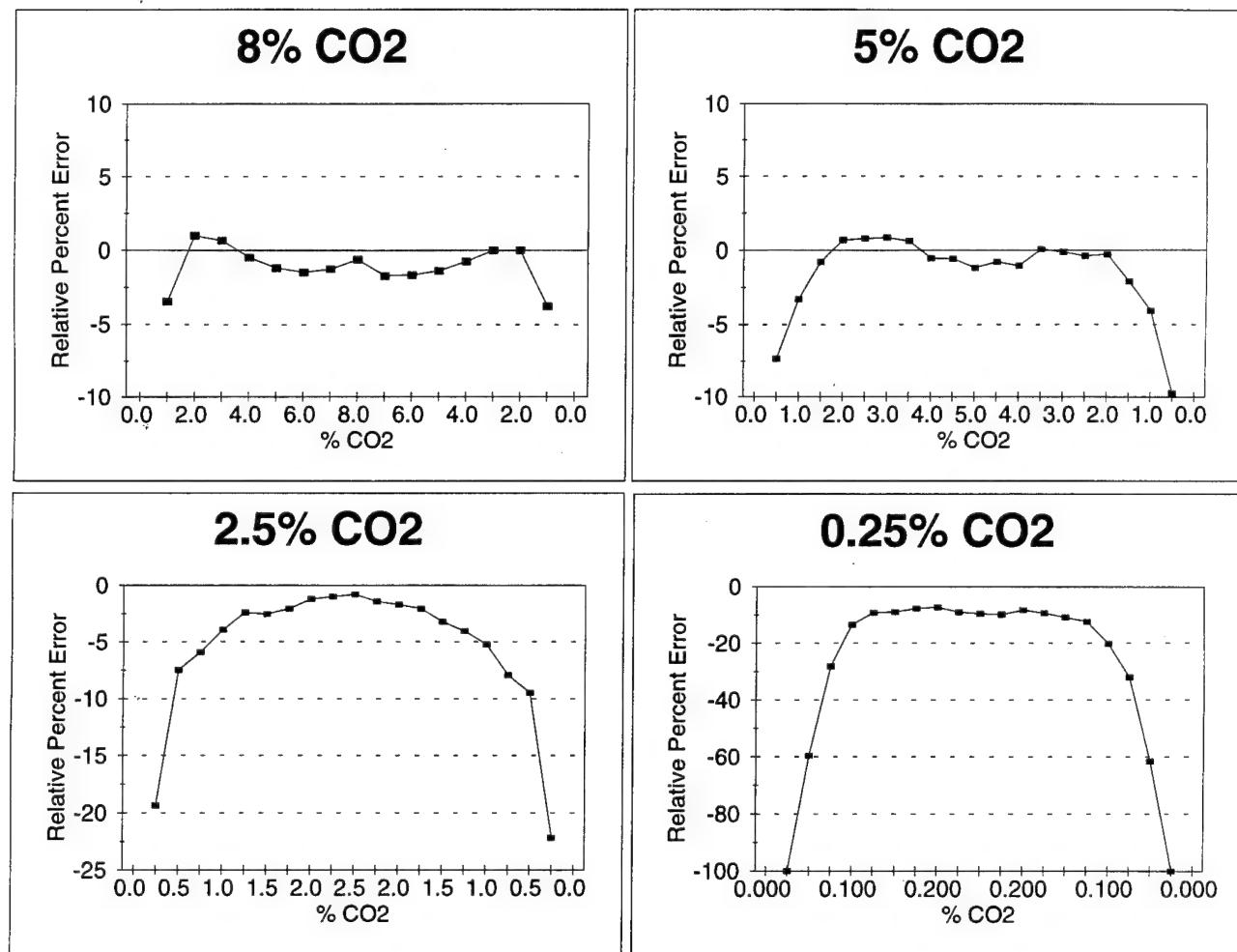
# Figure 3C Nova Response Curves



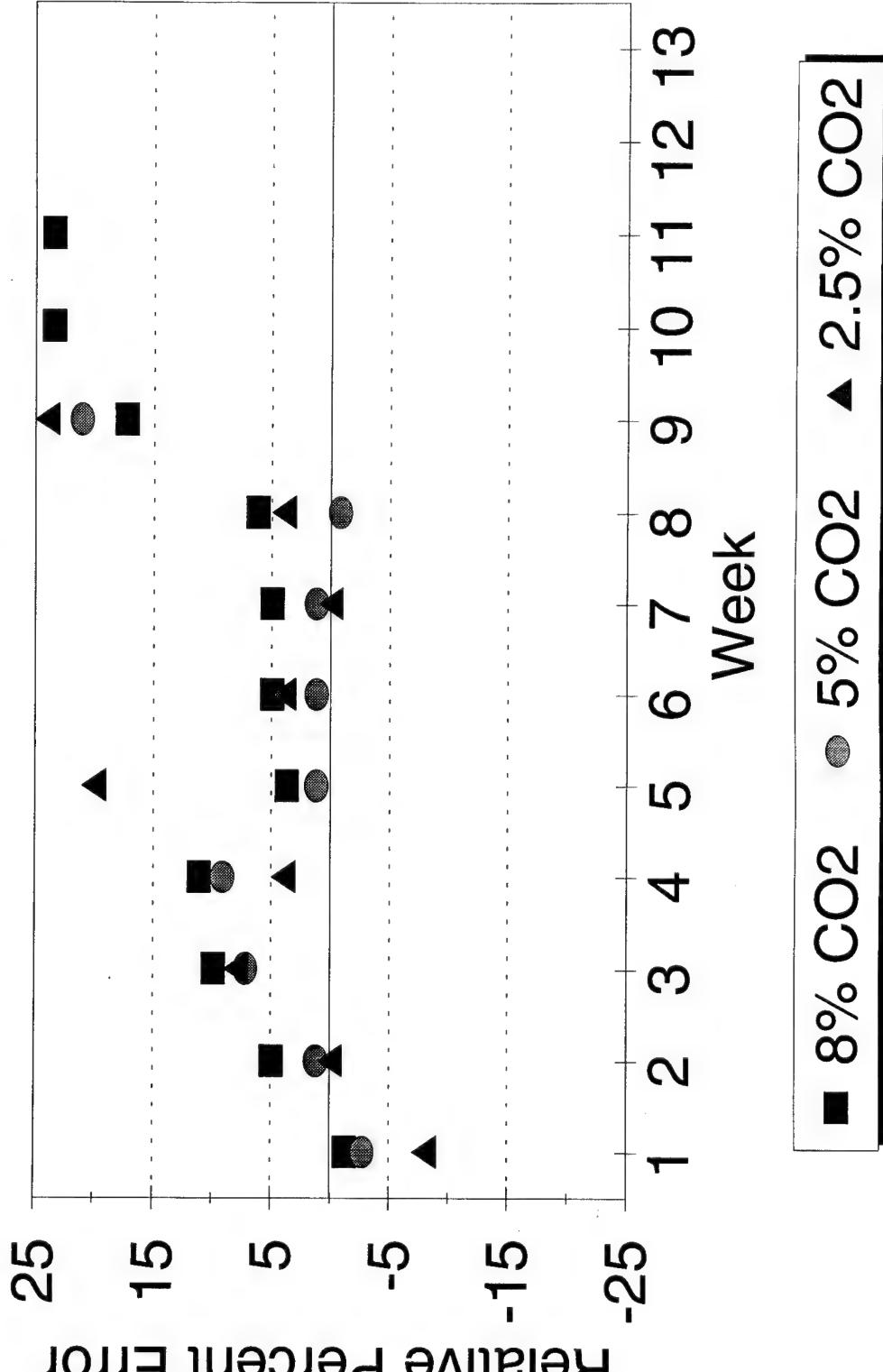
# Figure 3D GeoL Response Curves



# Figure 3E GeoS Response Curves

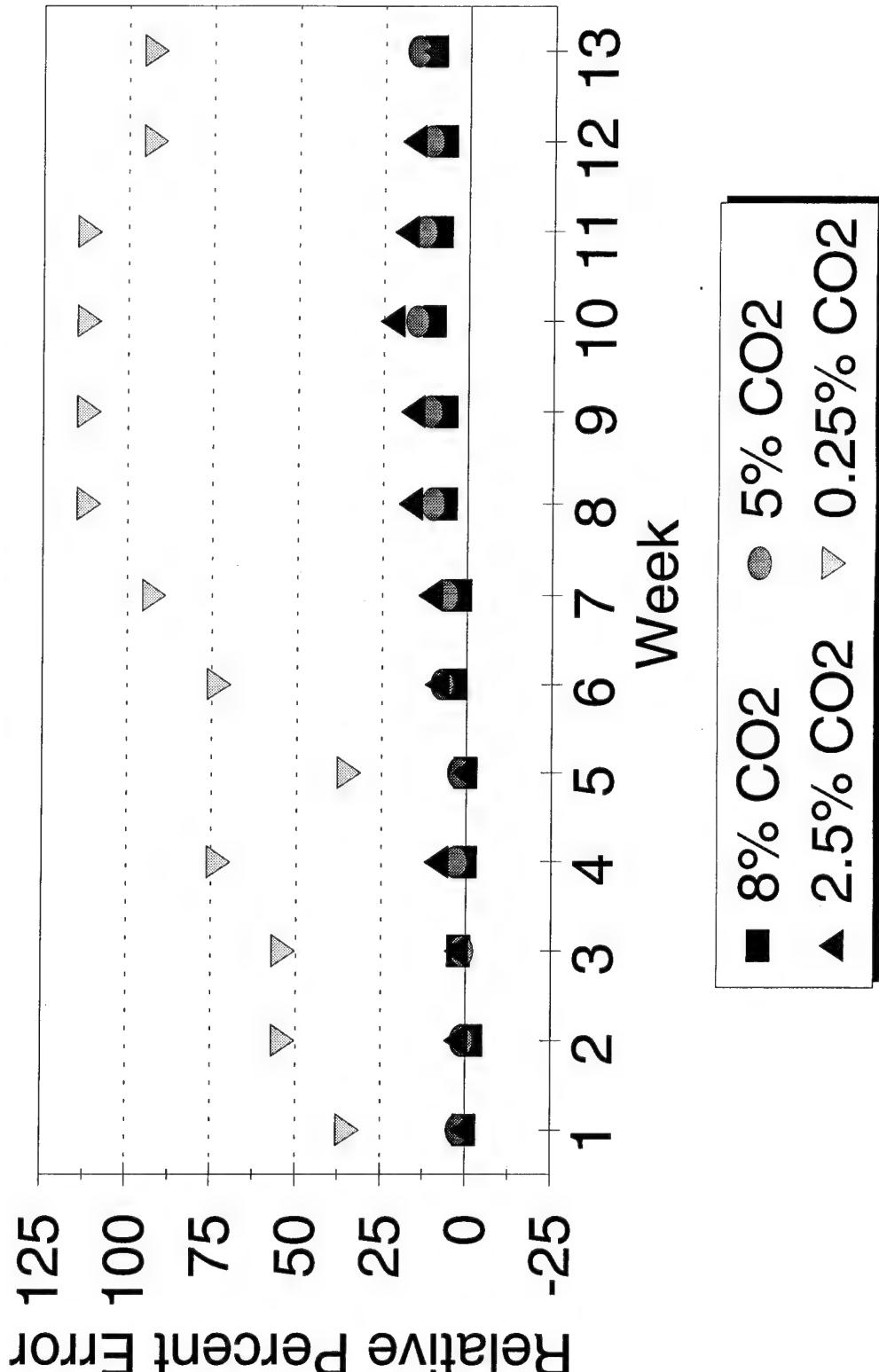


**Figure 4A**  
**Enmet Long-term Test**

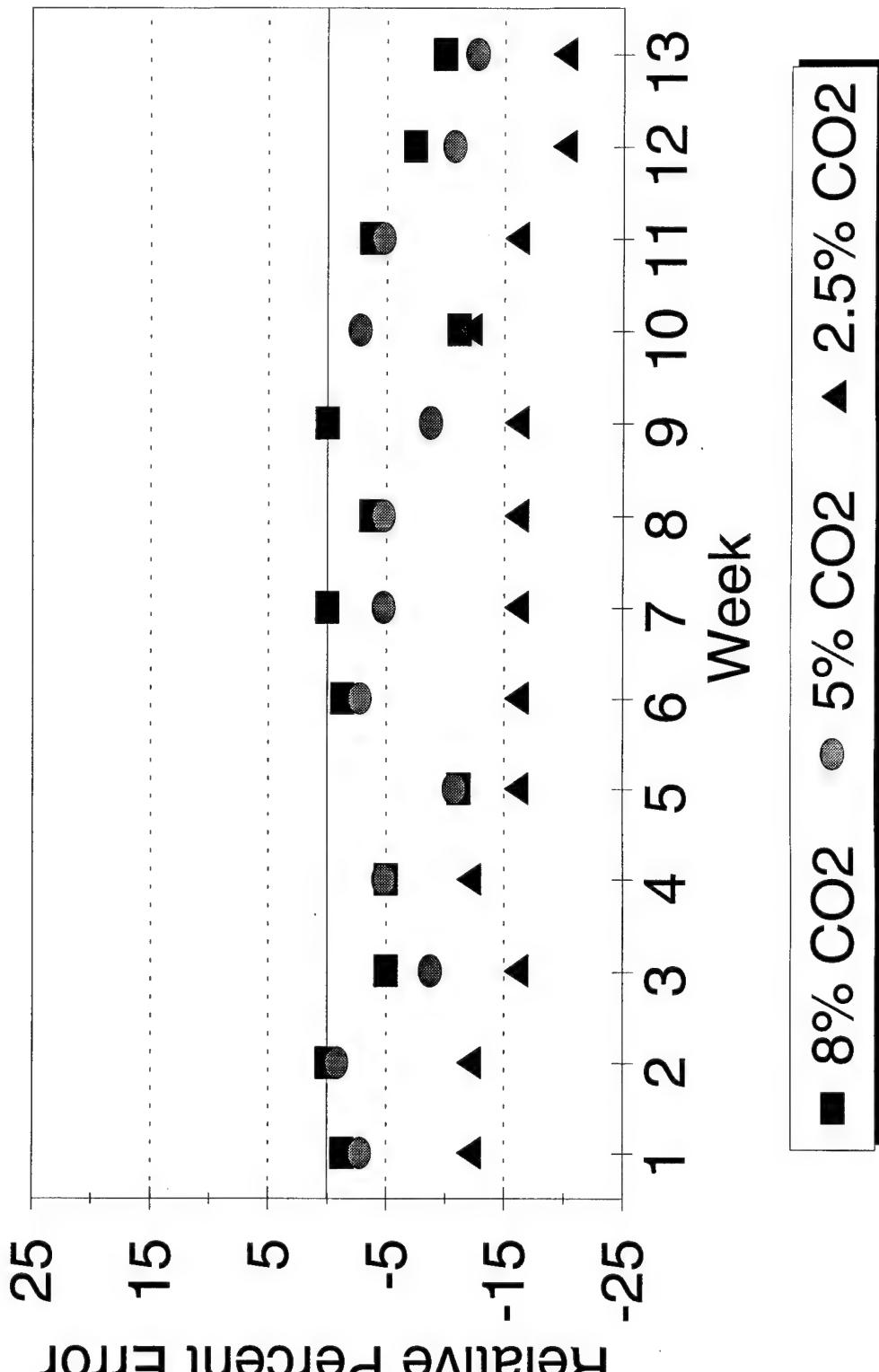


## Figure 4B

### RKI Long-term Test

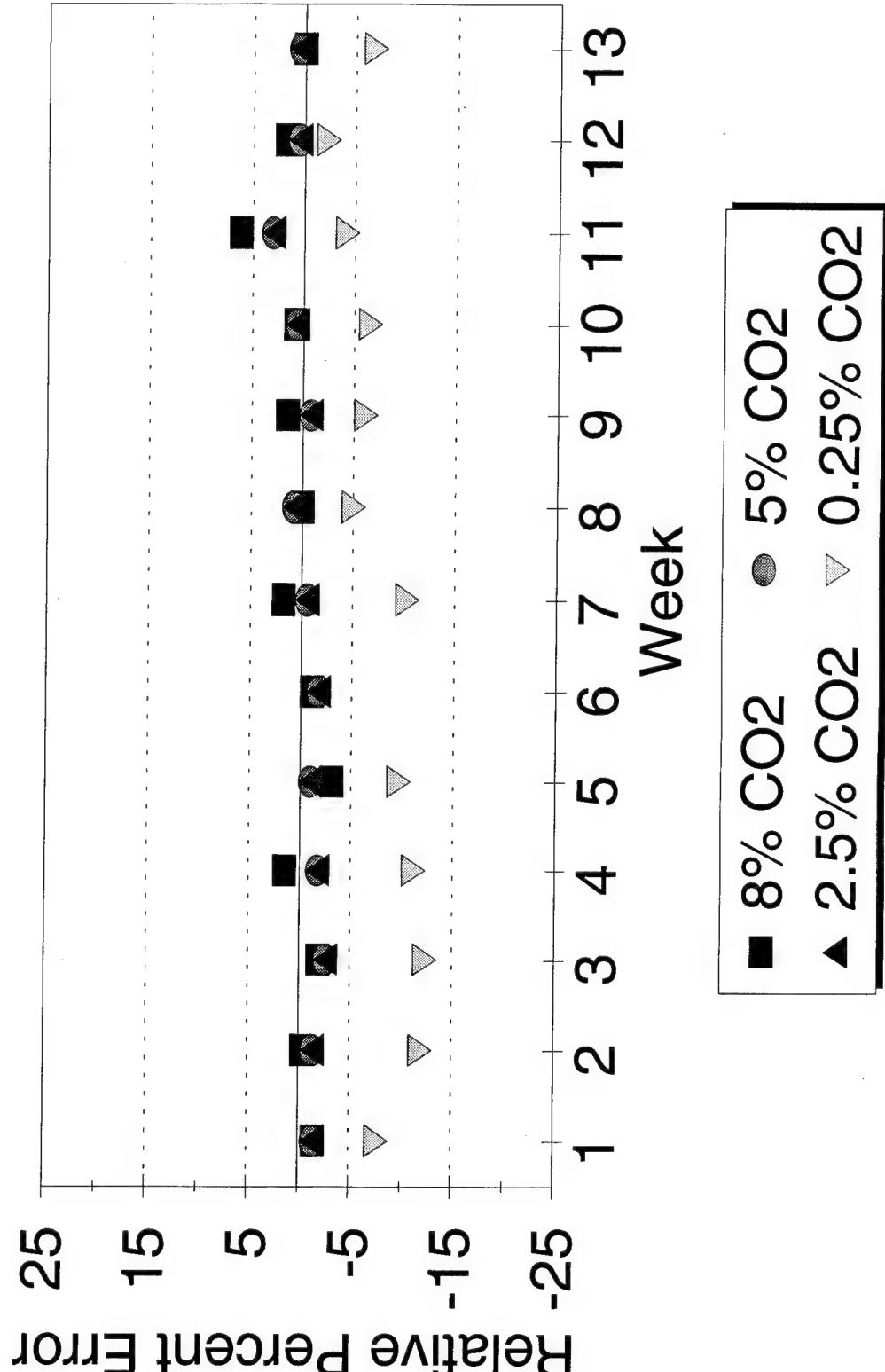


**Figure 4C**  
**Nova Long-term Test**

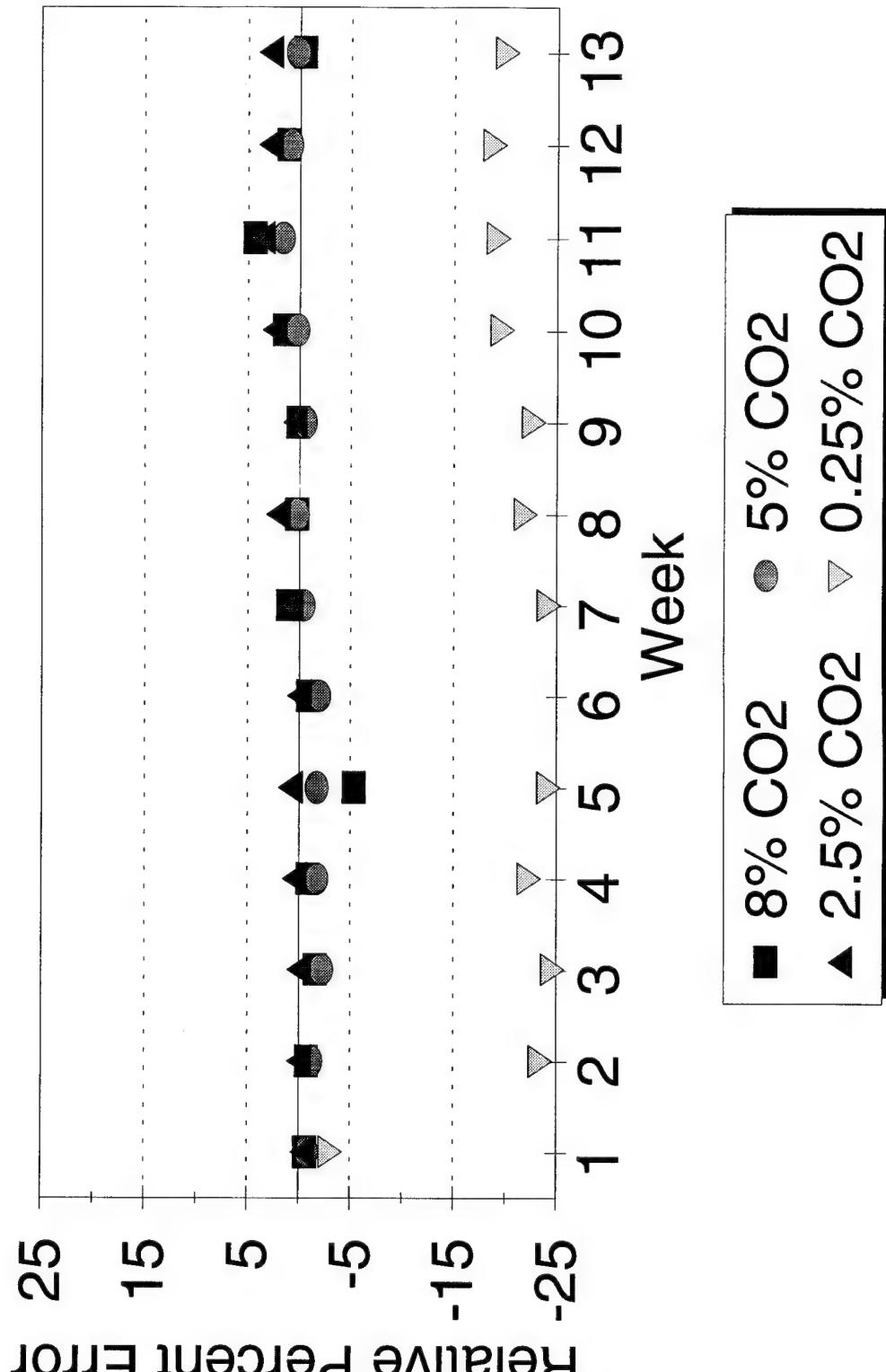


# Figure 4D

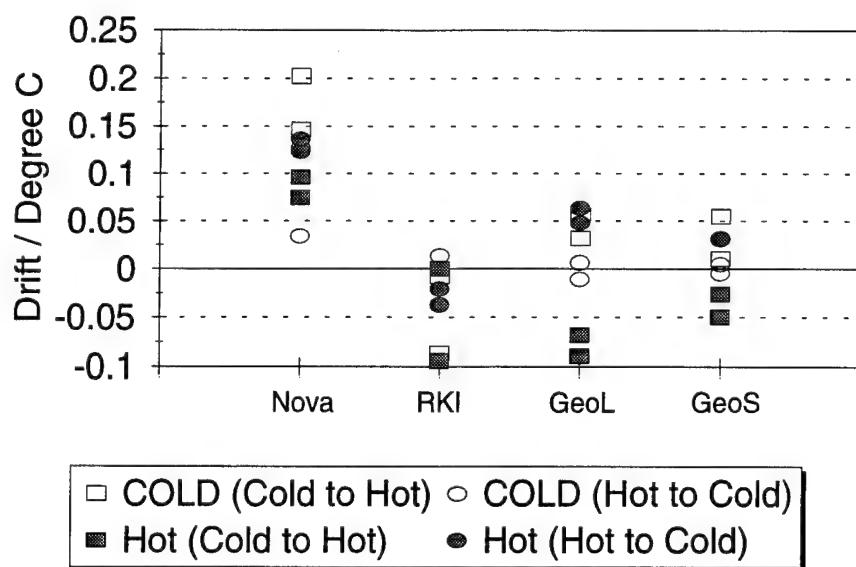
## Geol Long-term Test



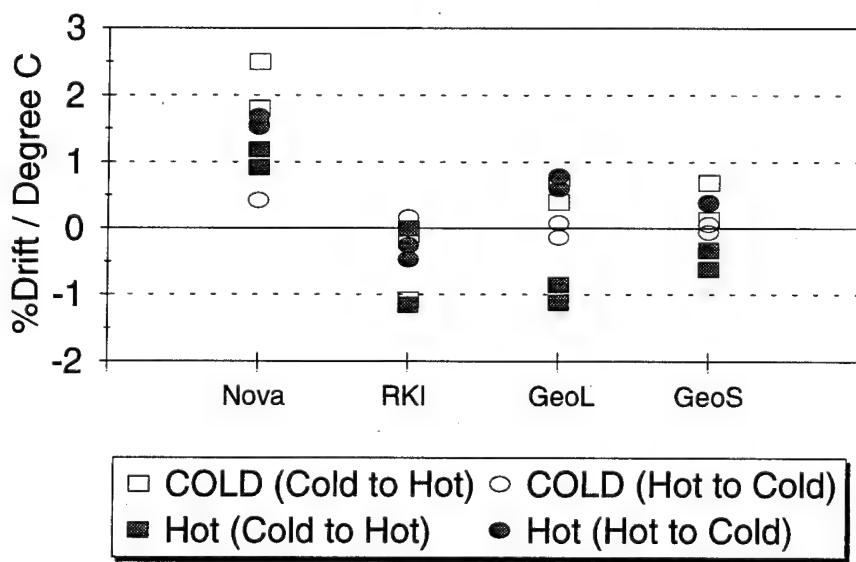
**Figure 4E**  
**GeoS Long-term Test**



**Figure 5A Temperature Test**  
**8% CO<sub>2</sub> - Drift / C**



**Figure 5B Temperature Test**  
**8% CO<sub>2</sub> - %Drift / C**



## **APPENDIX A: INSTRUMENT REVIEW AND SELECTION.**

The 5 candidates analyzers chosen for testing by NMRI are listed below.

<b>PAGE</b>	<b>MANUFACTURER</b>	<b>MODEL</b>
52	Enmet Corp.	CD-1300-P, 0 TO 10%
55 *	Geotechnical Inst. Inc.	CDM-1000/long, 0 to 7.5%
55	Geotechnical Inst. Inc.	CDM-1000/short, 0 to 7.5%
63	NOVA Analyt. Sys., Inc.	302 BD, 0 to 10%
64	RKI Instruments, Inc.	RIKEN RI-411A, 0 TO 9.95%

### **\*SELECTED AS BEST OF ALL CANDIDATES**

The following vendors make instruments that are either portable or transportable. Only a few make units that are portable and cover the full 10.0% range. None operate under hyperbaric conditions. Vendors that were contacted but do not have applicable instruments are listed at the end of the Appendix.

<b>PAGE</b>	<b>MANUFACTURER</b>
50	California Analytical (formerly: Milton Roy)
51	Columbus Instruments, Div. International Instr. Co.
52 *	Enmet Corp.
53	Enviromax/Tess-com, Inc.
54	Gas Tech, Inc.
55 **	Geotechnical Instruments, Inc.
56	Horiba Instruments Inc.
57	Illinois Instruments, Inc.
58	Landtec Inc.
59	Li-Cor Inc.
60	Metrosonics Inc.
61	MSA Instr.
62	National Draeger, Inc.
63 *	NOVA Analytical Systems, Inc.
64 *	RKI Instruments, Inc.
65	Sensidine, Inc.
66	Servomex Co.
67	Shimadzu Scientific Instruments, Inc.
68	Siemens Industrial Automation, Inc.
69	Telaire Systems, Inc.
70	Teledyne Brown Engineering, Analytical Instruments.

\* Tested as a candidate analyzer.

\*\* Tested and selected as the final and best of all candidates.

**California Analytical (formerly:Milton Roy)      Attn: Fred Christ**  
**1238 West Grove Ave.**  
**Orange, CA 92665-4134**  
**(714)-974-5560 FAX (714)-921-2531**

*Model:* ZFP-5  
*Price:* \$2990.00  
*Method:* NDIR  
*Ranges:* 0-2000, 0-5000 PPM, 0 to 2 % & 0 to 5 %(dual range)  
*Power:* 115 Vac or rechargeable battery  
*Sampling pump:* built in/10 s response  
*Alarms:* none  
*Display:* Analog  
*Accuracy:* ± 5% of full scale  
*Repeatability:* ± 5% of full scale  
*Zero drift at constant temp:* not specified  
*Zero drift temp effect:* not specified  
*Operating temp range:* 32-104 °F (0-40°C)  
*Storage temp:* not specified  
*Weight:* 13 lbs. (6 kg.)  
*Dims:* 8.5x6.1x10.4 in. (215x155x265mm)  
*Output signal:* 0-100mV DC  
*Calibration:* not specified  
*Cal controls:* zero & span

**TEST RESULTS:** On 1/21/92 the unit was briefly tested at NMRI/Lab 103. The test consisted of a few zero and span measurements which were within the stated accuracy on both ranges. The unit was placed in a small animal hyperbaric chamber and pressed to 100 FSW, during a short exposure (less than 10 minutes), the unit read a steady value (400 PPM). The unit was returned to room pressure and retests showed normal operation.

**Columbus Instruments, Div. International Instr. Co.**  
**950 N. Haque Ave.**  
**P.O. Box 44049**  
**Columbus, OH 43204**  
**(800)669-5011**  
**Fax (614)276-0529**

*Model:* Model-180/8200-D-30/8203-D-30  
*Price:* \$4,900.00  
*Method:* NDIR  
*Ranges:* 0-10%  
*Power:* 115 Vac only  
*Sampling Pump:* Internal/100-650 ml/min  
*Alarms:* none  
*Display:* digital  
*Accuracy:*  $\pm .01\%$   
*Repeatability:*  $\pm .04\%$   
*Zero drift at constant temp:* .03%  
*Zero drift temp effect:*  
*Operating temp range:*  
*Storage temp:*  
*Weight:* 22 lb/9.75 kg  
*Dims:* 11x11.5x14 in.  
*Output signal:* ?  
*Calibration:* ?  
*Cal controls:* zero/span

**TEST RESULTS:** None

**COMMENTS:** This is a "high accuracy" unit not suitable for this study.

**ENMET CORP.**  
**P.O. BOX 97**  
**680 Fairfield Ct.**  
**ANN ARBOR, MI 48867-0979**  
**(313)-761-1270 Fax (313)-761-3220**

*Model:* CD-1300-P portable carbon dioxide analyzer  
*Price:* \$1895.00  
*Method:* NDIR  
*Ranges:* Std,0-5000PPM, Opt, 0-10%, 0-20%, 0-100%  
*Power:* 9.6V rechargeable batt, operates 12 h on 1 charge, can be operated off of charger  
*Sampling pump:* built in with 500 cc/min flow  
*Alarms:* high & low gas, low flow  
*Display:* Analog  
*Accuracy:*  $\pm 3\%$  of full scale  
*Repeatability:*  $\pm 1\%$  of full scale  
*Zero drift at constant temp:* <0.2% CO<sub>2</sub> per mo.  
*Zero drift temp effect:* <0.2% CO<sub>2</sub> per deg. C  
*Operating temp range:* 15 to 140 °F (-10 to 60 °C)  
*Storage temp:* -5 to 160 °F (-20 to 70 °C)  
*Weight:* 3.5 lb (1.5 kg.)  
*Dims:* 3x5x8.5 in. (7.5x14x22cm.)  
*Output signal:* 0-1Vdc (0 to full scale, non-linear)  
*Calibration:* Every 3 to 4 months  
*Cal controls:* zero & span

**TEST RESULTS:** Difficult to calibrate.

**Enviromax/Tess-Com, Inc.**  
**18900 Teller Ave.**  
**Irvine, CA 92715**  
**(714)863-9443**  
**Fax (714)756-1635**

**Distributor:**  
**Tess-Com/Lou Colonna**  
**Butler, PA**  
**(412)233-5782**

*Model:* enviromax 3000  
*Price:* \$6395.00  
*Method:* NDIR  
*Ranges:* 0-10,000 PPM  
*Power:* Battery/rechargeable  
*Sampling Pump:* internal, 0.2-2 LPM  
*Alarms:* audible  
*Display:* digital  
*Accuracy:* ± 3 ppm or 0.1% of full scale  
*Repeatability:* ± 3 ppm  
*Zero drift at constant temp:* <3 ppm per 24 h  
*Zero drift temp effect:* not specified  
*Operating temp range:* -10 to 50 °C  
*Storage temp:* -10 to 80 °C  
*Weight:* 22 lbs. (10 kg)  
*Dims:* 20x8x5 in. (50x22x13)  
*Output signal:* 0-1,5,10Vdc  
*Calibration:* not specified  
*Cal controls:* zero/span

**TEST RESULTS:** none, but the navy has one in a Norfolk, VA facility.

**COMMENTS:** Agent claims the unit is "top of the line & state of the art", more data needed, price seems very high for this study. Demo available for portable and rack mounted CO<sub>2</sub>/O<sub>2</sub> version.

**Gas Tech, Inc.**  
**8407 Central Ave.**  
**Newark, CA 94560-3431**  
**(510)745-8700**  
**Fax (510)794-6201**

**Distributor:**  
**Jay Mottley.**  
**Carey Machinery, Co**  
**3501 Brehns Ave.**  
**Baltimore, MD 21213**  
**(410) 485-2323**

*Model:* 3252 Carbon Dioxide GasTechtor  
*Price:* \$3100.00  
*Method:* NDIR  
*Ranges:* 0 to 5% CO<sub>2</sub> and 0 to 25% O<sub>2</sub> is the only version made  
*Power:* Rechargeable battery  
*Sampling Pump:* built in  
*Alarms:* variable level  
*Display:* analog  
*Accuracy:* ± 10% Of full scale  
*Repeatability:* ± 5% of full scale  
*Zero drift at constant temp:* no info  
*Zero drift temp effect:* no info  
*Operating temp range:* 0-40 °C  
*Storage temp:* no info  
*Weight:* 8 lbs  
*Dims:* 12x4x6 in.  
*Output signal:* optional, 0-100mV  
*Calibration:* no info  
*Cal controls:* no info

**TEST RESULTS:** none

**COMMENTS:** The vendor only markets a dual sensor CO<sub>2</sub>/O<sub>2</sub> unit and the range is 0 to 5% which is too low for this application. One unit has been procured for the DDS project for evaluation as a backup unit.

**Geotechnical Instruments, Inc**  
**7507 Standish Pl.**  
**Rockville, MD 20855**  
**(301)309-6580**  
**Fax (301)309-6584**

**Distributor:**  
**Joel Johnson**  
**PEDC, Inc.**  
**P.O. Box 7026**  
**Wilmington, DE 19803**  
**(302) 655-9291 Fax 655-8140**

*Model:* CDM-1000  
*Price:* \$4300.00  
*Method:* NDIR  
*Ranges:* 0 to 7.5%  
*Power:* Battery/115Vac on recharger  
*Sampling Pump:* Internal @ 500-750 cc/min  
*Alarms:* none  
*Display:* digital  
*Accuracy:*  $\pm$  10% of measurement/verified  
*Repeatability:*  $\pm$  10% of measurement/verified  
*Zero drift at constant temp:* not checked  
*Zero drift temp effect:* ~+10 ppm/-1°F  
*Operating temp range:* 0-40 °C/32-104 °F  
*Storage temp:*  
*Weight:* 4.8 lb./2.2 kg  
*Dims:* 8.7x8.9x2 in./22x22.6x5.1 cm.  
*Output signal:* RS 232  
*Calibration:* TBD  
*Cal controls:* Span only

**TEST RESULTS:** Tested 10/25/94. Accuracy/Repeatability/drift tests on low/high, 1,250/20,000 PPM gas showed that the unit has a maximum error of  $\pm$  3% @ 1,250 PPM and  $\pm$  7% @ 20,000 PPM. Linearity tests from 500-2,500 PPM were  $\pm$  5% (below 500 PPM the error was 20%). From 5,000-25,000 PPM, the linearity was  $\pm$  6%. Zero/span checks were within spec for 2 days, then the zero became offset by 600 PPM. After a 48 hour off cycle, the zero returned to normal. A telecon with Chris Sweet (Geotch. U.K.) indicated the problem may have been infusion of the 25,000PPM span gas into the interior of the case. It then takes time for this gas to exit since the case is sealed with a gasket. This fault has been corrected.

**Horiba Instruments Inc.**  
**1021 Duryea Ave.**  
**Irvine, CA 92714**  
**(800)-446-7422**  
**Fax (714)-250-0924**

**Sales/Distributor:**  
**PENN-DEL**  
**810 N. Pine Ridge Ct.**  
**Bel Air, MD 21014**  
**(410)-893-7960**

**R.T. Gondon**  
**(410)437-8785**  
**(410)437-8785**

*Model:* MEXA-211GE  
*Price:* \$1995.00  
*Method:* NDIR  
*Ranges:* 0-19.995  
*Power:* 120Vac, not battery operated  
*Sampling pump:* built in  
*Alarms:* multiple, gas, etc.  
*Display:* digital  
*Accuracy:*  $\pm$  (not avail)  
*Repeatability:*  $\pm$  0.3% or  $\pm$  2%, whichever is greater  
*Zero drift at constant temp:* (not avail)  
*Zero drift temp effect:* (not avail)  
*Operating temp range:* 0-40 °C  
*Storage temp:* (not avail)  
*Weight:* approx 14.4 lb (6.5 kg)  
*Dims:* 10.3x6.3x14.2 in. (260x160x360cm.)  
*Output signal:* 0-1Vdc  
*Calibration:* not specified  
*Cal controls:* not specified

**TEST RESULTS:** none

**COMMENTS:** Demonstration requested 8/22/94. R. Gondon sent Horiba a second request for a demo 11/1/94.

**Illinois Instruments, Inc.**  
**27840 Concrete Dr.**  
**Ingleside, IL 60041**  
**(815)-344-6212**  
**Fax (815)-344-6332**

*Model:* 3700 Headspace Analyzer  
*Price:* \$4495.00  
*Method:* NDIR  
*Ranges:* 0-100%  
*Power:* 115Vac only  
*Sampling Pump:* internal  
*Alarms:* none  
*Display:* digital  
*Accuracy:*  $\pm 2\%$  of measured value  
*Repeatability:* not specified  
*Zero drift at constant temp:* not specified  
*Zero drift temp effect:* not specified  
*Operating temp range:* not specified  
*Storage temp:* not defined  
*Weight:* not given  
*Dims:* 11x10.5x4.5 in.  
*Output signal:* 0-10V  
*Calibration:* not specified  
*Cal controls:* zero & span

**TEST RESULTS:** none

**COMMENTS:** No battery option; demo available if desired.

**Landtec**  
**6055 E Washington Blvd.**  
**Commerce, CA**

**Distributor:**  
**Hazco services Inc.**  
**2006 Springboro West**  
**Dayton, OH 45439**  
**(513)-293-2700**  
**Fax (513)-293-9227**  
**Hot line (800)-332-0435**

*Model:* GA-90 Gas Analyzer  
*Price:* \$4875.00  
*Method:* NDIR  
*Ranges:* 0-75%  
*Power:* Battery only ?  
*Sampling Pump:* Internal  
*Alarms:* wet gas  
*Display:* digital  
*Accuracy:* ± 3%(per telecon, in 0-10% may be o.k.)  
*Repeatability:* not specified  
*Zero drift at constant temp:* not specified  
*Zero drift temp effect:* not specified  
*Operating temp range:* 32 - 104 °F  
*Storage temp:* not specified  
*Weight:* "light weight"  
*Dims:* "compact"  
*Output signal:* none  
*Calibration:* not specified  
*Cal controls:* not described

**TEST RESULTS:** No test.

**COMMENTS:** This unit is made by Geotechnical Instruments and is similar to Geotechnical CDM-1000. Landtec is the U.S. distributor.

**LI-COR, Inc.**  
**4421 Superior St.**  
**P.O. Box 4425**  
**Lincoln, NE 68504**  
**(800)-447-3576 (402)-467-3576 FAX (402)-467-2819**

*Model:* LI-6252/LI-670  
*Price:* \$7300.00/\$2375.00  
*Method:* NDIR  
*Ranges:* 0-1000 & 0-5000 ppm  
*Power:* 120 Vac & rechargeable batt. pack (10.5 - 16Vdc)  
*Sampling pump:* dual, variable flow, for sample & reference (if needed)  
*Alarms:* none  
*Display:* digital  
*Accuracy:* ±5 ppm  
*Repeatability:* ±1 ppm  
*Zero drift at constant temp:* <10 ppm per 24 h  
*Zero drift temp effect:* 0.5 ppm per °C  
*Operating temp range:* not specified  
*Storage temp:* not specified  
*Weight:* 7.7 lb (3.5 kg.)  
*Dims:* 13x33.5x24cm.  
*Output signal:* RS-232c,100mV,5V,±15V (non-linear) & 4-20 mA  
*Calibration:* daily  
*Cal controls:* Zero, span

**TEST RESULTS:** A 6252/670 combination has been used for 2 years as a bench top unit with no problems. Accuracy and stability are to specification.

**COMMENTS:** This system is NOT rugged, corpsman friendly or low cost. This system should be used as a performance standard with which candidate analyzers should be compared.

<b>Metrosonics Inc.</b>	<b>Distributor</b>
General Products Div.	NCP/Analytical Inst. Inc.
P.O. Box 23075	512 Interchange Blvd.
Rochester, NY 14692	Newark, DE 19711
(716)-334-7300	(800)-346-0304
Fax (716)-334-2635	Fax (302)-733-0948

<i>Model:</i>	aq-511
<i>Price:</i>	\$2290.00 (with batt. pack)
<i>Method:</i>	NDIR
<i>Ranges:</i>	0-5000 ppm
<i>Power:</i>	114Vac & battery pack
<i>Sampling Pump:</i>	Internal @ 1 LPM
<i>Alarms:</i>	high gas option
<i>Display:</i>	digital
<i>Accuracy:</i>	± 3% of full scale
<i>Repeatability:</i>	± not specified
<i>Zero drift at constant temp:</i>	not specified
<i>Zero drift temp effect:</i>	not specified
<i>Operating temp range:</i>	32 - 122 °F (0-50 °C)
<i>Storage temp:</i>	-4 - 140 °F ((-20)-60 °C)
<i>Weight:</i>	8.2 lb (3.7 kg)
<i>Dims:</i>	10.1x12.3x4 in. (25.7x31.2x10.3 cm)
<i>Output signal:</i>	0 - 1V
<i>Calibration:</i>	daily
<i>Cal controls:</i>	Zero & span

**TEST RESULTS:** None

**COMMENTS:** This unit does not cover the full range (7.5%)

**MSA Instruments**  
**P.O. Box 426**  
**Pittsburgh, PA 15230**  
**(800)-672-2222**

**Portable Regional Office**  
**MSA/36 Great Valley Rd.**  
**Malvern, PA 19355**  
**(800)-672-2222 (ask for Malvrm)**  
**FAX (610)-647-8893**

*Model:* ACO<sub>2</sub> Hand Held Indicator  
*Price:* \$1600.00  
*Method:* Electrochemical pH sensor  
*Ranges:* 0.03% to 100%  
*Power:* 4AA batteries  
*Sampling Pump:* diffusion or hand pump  
*Alarms:* dual gas levels & low battery  
*Display:* digital  
*Accuracy:* ± 0.02% @ 10% range  
*Repeatability:* ± not specified  
*Zero drift at constant temp:* not specified  
*Zero drift temp effect:* not specified  
*Operating temp range:* 32-113 °F (0-45 °C)  
*Operating Pressure range:* 700-1060 hPa  
*Storage temp:* not specified  
*Weight:* 11 oz. (310 gm.)  
*Dims:* 2.3x1.6x6.2 in. (60x42x160 cm.)  
*Output signal:* none  
*Calibration:* unknown  
*Cal controls:* not specified

**TEST RESULTS:** none

**COMMENTS:** sensor life is one year; electrolyte must be replaced every 3 mos.

**National Draeger, Inc.**  
**101 Technology Dr.**  
**P.O. Box 120**  
**Pittsburgh, PA 15230**  
**(800)-922-5518**  
**Fax (800)-922-5519**

**Distributor:**  
**NCP/Analytical Instr. Inc.**  
**512 Interchange Blvd.**  
**Newark, DE 19711**  
**(800)-346-0304**  
**(302)-733-0948**

*Model:* Multiwarn Portable Gas Monitor  
*Price:* \$5300.00  
*Method:* Unknown  
*Ranges:* 0-9999 PPM  
*Power:* Battery only  
*Sampling Pump:* Internal and diffusion  
*Alarms:* low flow and gas  
*Display:* digital  
*Accuracy:* no data  
*Repeatability:* no data  
*Zero drift at constant temp:* no data  
*Zero drift temp effect:* no data  
*Operating temp range:* (-5)- 105 °F (-20 to 40 °C)  
*Storage temp:* not specified  
*Weight:* 3.1 lbs. (1.4 kg)  
*Dims:* 4.9x7.5x2.5 in. (12.4x19.0x6.3 cm)  
*Output signal:* PC interface  
*Calibration:* unknown  
*Cal controls:* unknown

**TEST RESULTS:** none

**COMMENTS:** Pricey...Demo requested 9/12/94

**NOVA Analytical Systems, Inc.**  
**1925 Pine Ave.**  
**Niagra Falls, NY 14301**  
**(800)295-3771**  
**Fax (716)282-2937**

*Model:* 302BD Portable CO<sub>2</sub> Analyzer  
*Price:* \$2645.00  
*Method:* NDIR  
*Ranges:* 0-10%  
*Power:* 115Vac & battery  
*Sampling Pump:* internal/  
*Alarms:* none  
*Display:* digital  
*Accuracy:* ± 2% of full scale  
*Repeatability:* ± 2% of full scale  
*Zero drift at constant temp:* 30 ppm per hour  
*Zero drift temp effect:* 2 ppm per deg. F  
*Operating temp range:* 32-120 °F (0-50 °C)  
*Storage temp:* -20 to 130 °F (-30 to 55 °C)  
*Weight:* 6 lb  
*Dims:* 10x7.5x8 in.  
*Output signal:* 0-1Vdc  
*Calibration:* suggested "yearly"  
*Cal controls:* span only

**TEST RESULTS:** During screening, the unit performed within 10% from 1 to 5%. Below 1%, the error was 20%. Accuracy & repeatability were better than 5%. Drift, short term, is not as good as desired, but is well within the required range. A daily calibration span check after a 30 min warm-up is recommended for best results.

**RKI Instr. Inc.**  
1855 Whipple Rd.  
Hayward, CA 94544  
(800)754-5165  
Fax(510)441-5650

**Distributor**  
Advanced Control Technology  
P.O. Box 85  
2151 Johnson Rd.  
Rockville, VA 23146  
(804)-749-3434

*Model:* RIKEN RI-411A  
*Price:* \$3075.00  
*Method:* NDIR  
*Ranges:* 0-10%  
*Power:* 120Vac & batt. pack  
*Sampling Pump:* Internal diaphragm (1.2 LPM)  
*Alarms:* High CO<sub>2</sub> & Low batt  
*Display:* digital  
*Accuracy:* ± 2% of full scale  
*Repeatability:* ± 2% of full scale  
*Zero drift at constant temp:* not specified  
*Zero drift temp effect:* not specified  
*Operating temp range:* 14-104 °F (-10-40 °C)  
*Storage temp:* not specified  
*Weight:* 6 lb  
*Dims:* 10x7.5x4.5 in.  
*Output signal:* 0-10 Vdc linear  
*Calibration:* Based on tests, a daily check is desirable  
*Cal controls:* Zero & Span

**TEST RESULTS:** The loaner tested did not have a 115Vac adapter so all tests were done with alkaline batteries. Linearity, accuracy and repeatability were within 5%. Even long term, zero drift was excellent.

**Sensidine, Inc.**  
**16333 Bay Vista Dr.**  
**Clearwater, FL 34620**  
**(800)-451-9444**  
**Fax (813)-539-0550**

*Model:* SS2000, Portable Gas Detector  
*Price:* ???  
*Method:* Electrochemical  
*Ranges:* 1,000-10,000 PPM  
*Power:* Battery/optional 115Vac  
*Sampling Pump:* none/diffusion  
*Alarms:* 5,000 ppm  
*Display:* analog  
*Accuracy:* ± 10%  
*Repeatability:* ± 10%  
*Zero drift at constant temp:* not specified  
*Zero drift temp effect:* not specified  
*Operating temp range:* 23-113 °F (-5 - 45 °C)  
*Storage temp:* not specified  
*Weight:* 3.4 lbs. (1.5kg)  
*Dims:* 8.5x4.4x6.8 in. (21.6x10.9x17.3 cm)  
*Output signal:* none  
*Calibration:* not specified  
*Cal controls:* not defined

**TEST RESULTS:** none

**COMMENTS:** electrochemical sensor has 3 year life. The lower range seems to start at 1000 PPM, more info is needed.

**Servomex Co.**  
**90 Kerry Pl.**  
**Norwood, MA 02062**  
**(617)-769-7710 FAX(617)-769-2834**

<i>Model:</i>	PA404
<i>Price:</i>	\$7500.00
<i>Method:</i>	NDIR
<i>Ranges:</i>	Varied, 0-10% available
<i>Power:</i>	120Vac & internal batt
<i>Sampling Pump:</i>	Internal (0.1-1 LPM)
<i>Alarms:</i>	High gas
<i>Display:</i>	digital
<i>Accuracy:</i>	± 1% full scale
<i>Repeatability:</i>	± 1% full scale
<i>Zero drift at constant temp:</i>	5%/7 Days
<i>Zero drift temp effect:</i>	0.3%/°C
<i>Operating temp range:</i>	32-104 °F (0-40 °C)
<i>Storage temp:</i>	not specified
<i>Weight:</i>	12.1 lbs. (5.5 kg)
<i>Dims:</i>	7.25x7.8x15 in. (185x220x390 mm)
<i>Output signal:</i>	0-100 mV
<i>Calibration:</i>	daily/not specified
<i>Cal controls:</i>	zero span

**TEST RESULTS:** This unit was given zero drift tests over an 8-hour period. On 120Vac, the unit had 0.1% drift and a second test showed no measurable drift when on battery operation for the same time.

**COMMENTS:** This unit was heavy with an unusual shape and costly, but its performance is excellent. Cost and size excluded it from consideration for this project.

**Shimadzu Scientific Inst. Inc**  
**7102 Riverwood Drive**  
**Columbia, MD 21046**  
**(800)-477-1227**  
**Fax (301)-381-1222**

Model:	CGT-10-3A
Price:	\$9500.00
Method:	NDIR
Ranges:	dual up to 100% in 1/5 ratio
Power:	115Vac only
Sampling Pump:	internal @2.5 LPM
Alarms:	none
Display:	analog
Accuracy:	± 2% of full scale
Repeatability:	± 2% of full scale
Zero drift at constant temp:	not specified
Zero drift temp effect:	not specified
Operating temp range:	5-40 °C
Storage temp:	not specified
Weight:	15 kg
Dims:	23x20x45 cm.
Output signal:	0-1Vdc
Calibration:	not specified
Cal controls:	not specified

**TEST RESULTS:** none

**COMMENTS:** no battery option.

**Siemens Industrial Automation, Inc.**  
100 Technology Dr.  
Alpharetta, GA 30202  
(404)740-3932  
Fax (404)3998

**Distributor:**  
Flow Tech  
Hunt Valley, MD

*Model:* ULTRAMAT 21/O<sub>2</sub>  
*Price:* \$4600.00  
*Method:* NDIR  
*Ranges:* 0-10%  
*Power:* 120Vac only  
*Sampling Pump:* Internal  
*Alarms:* 2 per channel  
*Display:* digital  
*Accuracy:* ± 1% of reading  
*Repeatability:* ± 1% of reading  
*Zero drift at constant temp:* 0.2% of range per week  
*Zero drift temp effect:* not specified  
*Operating temp range:* not specified  
*Storage temp:* not specified  
*Weight:* 20 lb (9 kg)  
*Dims:* 17.2x6.6x11.4 in. (44x17x29 cm)  
*Output signal:* analog 0-20ma  
*Calibration:* zero/daily; span/yearly  
*Cal controls:* zero/span

**TEST RESULTS:** A 21/02 analyzer with 0-20% CO<sub>2</sub>, 0-25% O<sub>2</sub> and 0-20 ppm CO ranges was tested 10/4 to 10/6 '94. A 20% CO<sub>2</sub> cal gas would be needed to set/check the span and none was available, so the unit was tested using its as received span setting. The unit was evaluated with a 5% CO<sub>2</sub> gas using the STEC gas divider to make dilutions. The test results were excellent. The unit was tested with 10 ppm CO/2540 ppm CO<sub>2</sub> and gave excellent results. Short term repeatability was exact over the 0-5% range.

**COMMENTS:** The unit must be autocaled daily with zero gas for good low level accuracy and again whenever the environmental conditions change. The unit, with 3 analyzers, is very heavy. It must be operated in the horizontal, on a flat surface. A short 2 in. drop test showed zero deflection of the display.

**Telaire Systems, Inc.**  
6489 Calle Real  
Goleta, CA 93117  
(800)472-6075  
(805)964-1699  
Fax (805)964-2129

**Distributor:**  
Jo Mitchel  
**P J Envirolytics**  
Hamburg, N.J.  
(201)209-1444

*Model:* 1050 CO<sub>2</sub> Monitor  
*Price:* \$500.00  
*Method:* NDIR  
*Ranges:* 0-1999 PPM  
*Power:* Battery with 115Vac recharger operation  
*Sampling Pump:* none/diffusion  
*Alarms:* user set single point alarm  
*Display:* digital  
*Accuracy:* ± 50 ppm  
*Repeatability:* ± 20 ppm  
*Zero drift at constant temp:* 100 ppm/year  
*Zero drift temp effect:* not specified  
*Pressure dependence:* +0.19% reading per mm Hg.  
*Operating temp range:* 32-122 °F (0-50 °C)  
*Storage temp:* 140 to 140 °C (-40 to 60 °C)  
*Weight:* 22 oz. (624 gm)  
*Dims:* 7.5x3.8x3 in. (19x9.7x7.6 cm)  
*Output signal:* 0-2Vdc @ 0-1999 PPM (2-4Vdc @ 2000-5000 PPM)  
*Calibration:* ? yearly ??  
*Cal controls:* zero/span

**TEST RESULTS:** none

**COMMENTS:** This unit does not cover desired range, but has a very attractive price. The vendor will not supply loaners nor help in finding a local user (they are not computerized to search a user file).

**Teledyne Brown Engineering, Inc.**

**Analytical Instruments**

**16830 Chestnut St.**

**Box 1580**

**City of Industry, CA 91749-1580**

**(818)961-9221**

**Fax (818)961-2538**

*Model:* 730 Series  
*Price:* \$3450.00 and up  
*Method:* NDIR  
*Ranges:* 0-10% and others  
*Power:* 115Vac, can supply a 24Vdc power version  
*Sampling Pump:* ?  
*Alarms:* none/?  
*Display:* digital  
*Accuracy:*  $\pm 2\%$  F.S.  
*Repeatability:*  $\pm 1\%$  F.S.  
*Zero drift at constant temp:* 1% F.S./week  
*Zero drift temp effect:*  
*Operating temp range:* 5 to 45 °C(41-113 °F)  
*Storage temp:*  
*Weight:* 20 lb  
*Dims:* models vary  
*Output signal:* 4-20mAdc, 0-1Vdc  
*Calibration:* daily/?  
*Cal controls:* ?

**TEST RESULTS:** none

**COMMENTS:** This sensor is used in the Hamilton Standard space backpack to replace the old Beckman sensor.

## **COMPANIES CONTACTED BUT ANALYZERS REJECTED**

The companies listed below were contacted for the CO<sub>2</sub> analyzer survey, but their units were rejected for various reasons.

1. AIM USA  
P.O. Box 720540  
Houston, TX 77272-0540  
(800)274-4246  
Hand held but do not do CO<sub>2</sub>.
2. Bachrach, Inc.  
625 Alpha Dr.  
Pittsburgh, PA 15238-2878  
(412)963-2157  
Their units are for stack gas monitoring primarily.
3. Biosystems, Inc.  
5 Brookside Dr.  
Middlefield, CT 06455  
(203)344-1079  
Their units do not do CO<sub>2</sub>.
4. Brue & Kjaer  
185 Forest St.  
Marlborough, MA 01752  
(508)-481-7000  
An in-house demonstration of the B & K Model 1302 analyzer was a complete failure. No consideration was given to this unit following the demo.
5. Columbus Instruments  
Columbus, OH  
(614)488-6176  
Their "Ferm-180" is 115VAC, high accuracy/high sensitivity unit for 0-15% CO<sub>2</sub>/0-20% O<sub>2</sub>. No portable units.
6. COSMOS/Sam Dick Industries, Inc.  
1140 N.W. 46th St.  
Seattle, WA 98107  
(206)789-5410  
Fax (206)7895414  
An interesting device that uses a sensitive thermal conductivity detector to measure the composition of one gas in another. It is non-specific so of no use in this study but may be a simple easy-to-use item to replace a total hydrocarbon analyzer.

7. Enviro Systems Ltd.  
Electron House  
Higher Hilgate Stockport  
Cheshire SK1 3QD England  
44(0)61 474 7477

They make a unit which can measure NH<sub>3</sub>, formaldehyde, etc. of unspecified methodology. It is not applicable to this program, but might apply to a program to quantitate special species not generally found by the normal test procedures.
8. Foxboro Co.  
P.O. Box 500  
East Bridgewater, Ma 02333  
(508)-378-5556

These units are too large and do not cover the 7.5% range.
9. GAC/General Analysis Corp  
140 Water St.  
South Norwalk CT 06854  
(203)-852-8999

They do not have a portable unit and do not want to make one. Their fixed unit was too large to be moved easily.
10. Gasalarm Systems Corp.  
Houston, Texas  
(713)-364-1988

They do not have an off the shelf fixed or portable unit for this application.
11. HNU Systems, Inc.  
160 Charlemont St.  
Newton, MA 02161-9987  
(800)724-5600

They make PID's & portable GC's, not germane to this study.
12. IMR/Environmental Equipment, Inc.  
5401 Central Ave.  
St. Petersburg, FL 33710  
(813)328-2818

A nice looking stack gas analyzer of no interest.
13. MDA Scientific, Inc.  
Evanston, ILL  
(800)344-4632

They do not make any CO<sub>2</sub> analyzers.

14. MTI/Microsensor Tech. Corp.  
41762 Christy St.  
Fremont, CA 94538  
(510)-490-0900  
Portable GC for fixed gas analysis. Too \$ and complicated.
15. Neotronics  
2144 Hilton Dr. SW  
Gainsville, GA 30501-6153  
(800)-535-0606  
This company did not reply to a request for information.
16. Penn-Del Inst. Sales Inc.  
709 Bethlehem Pike  
Philadelphia, PA 19118  
(215)-836-9100  
Tested Horiba Model APBA-210 in house. Unit does not cover the 7.5% range and showed poor performance and poor zero stability.
17. Photovac, Inc.  
25-B Jefrynn Blvd. West  
Deer Park, NY 11729  
(516)254-4199  
These units are portable hand held gas chromatographs that are too complicated for the specified use.
18. Rosemount Analytical Inc.  
600 South Harbor Blvd.  
Le Habre, CA 90631  
(213)-690-7600  
No portables. No movable fixed units.
19. Sierra Monitor, Inc.  
1991 Tarob Ct.  
Milpitas, CA 95035  
(408)262-6611  
No portable units; remote sensors & controllers only.
20. Teledyne Analytical Instruments, Inc.  
Pasadena, CA  
(818)961-9221  
Most of their units are combustion analyzers that do not measure CO<sub>2</sub> directly, but calculate it from a combustion equation. Not applicable to this study. Their "Mini-IR" sensor does apply.

21. Thermal Environmental Inst. Inc.  
8 West Forge Pkwy.  
Franklin, MA 02038  
(508)-520-1460  
Low range, large, expensive, fixed units only.
22. Universal Sensors, Inc.  
5258 Veterans Blvd.  
Mt. Airie, LA 70006  
(504)885-8443  
They do not make a portable CO<sub>2</sub> analyzer.

## **APPENDIX B: FIELD TESTING PROTOCOL.**

### **FIELD TESTING INFO FOR SUBMARINE PORTABLE CO<sub>2</sub> ANALYZER**

NMRI POC: Dr. Richard Lillo  
Naval Medical Research Institute  
Code 541  
8901 Wisconsin Ave.  
Bethesda, MD 20889-5607  
(301) 295-5883/-5882  
DSN 295-5883/-5882

#### ***1. Background***

NMRI was tasked by NSMRL to identify a portable CO<sub>2</sub> analyzer for use on U.S. Navy submarines. This task involved a market search, instrument testing in the laboratory, and now field testing of the candidate analyzer, the Geotechnical Infra-red Analyzer. This analyzer measures CO<sub>2</sub> up to 7.5%.

#### ***2. Your job***

Your job is to help us by performing the field test which will be done on at least one U.S. sub. Results from your testing will help to evaluate:

- a. how "sailor friendly" the analyzer is
- b. stability of instrument under actual sub conditions
- c. potential problems with draft procedures
- d. comparison of analyzer and CAMS-I CO<sub>2</sub> measurements

#### ***3. Equipment***

- a. 1 Geotechnical CO<sub>2</sub> analyzer for 1 ATA use
- b. Battery charger for analyzer
- c. Sampling tubing
- d. Data sheets

#### ***4. Test Plan***

- a. Check calibration (do not recalibrate) once a day prior to use.
- b. Following calibration check, take CO<sub>2</sub> measurements throughout the sub spaces.
- c. Record (when possible) simultaneous CAMS-I readings for spaces where portable CO<sub>2</sub> analyzer is used.

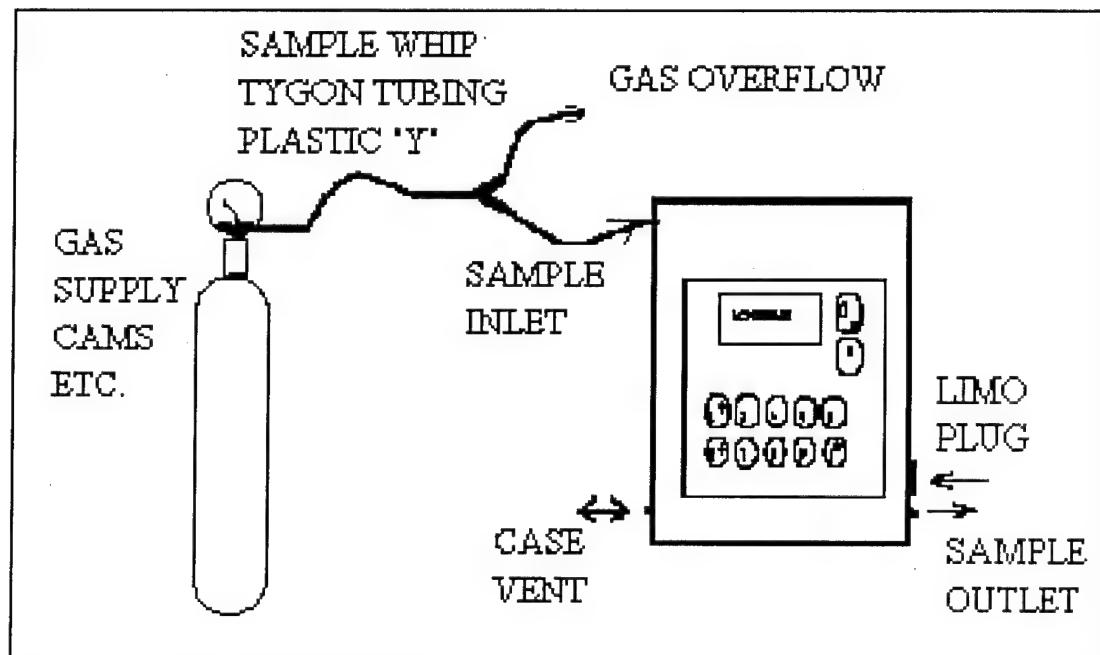
## *Instrument procedures*

### *Batteries/charging.*

The CO<sub>2</sub> analyzer is normally run off its self-contained NiCad batteries. However, when the batteries require charging, the analyzer can be used when it is attached to the charger. The charger plugs into 110 volt line current. The instrument must have batteries in place to operate. Ideally, NiCad batteries should be fully discharged and recharged during operation rather than continually topped off without a full discharge. However, this probably will not be possible - don't worry. An overnight charging should provide 12 h of usage.

### *Calibration check.*

1. Instrument has been calibrated at NMRI. Do not recalibrate.
2. Locate the CAMS-I calibration gas and install on its regulator the tubing we have supplied. This tubing contains a tee to allow sampling with the analyzer. Connect the inlet port of the CO<sub>2</sub> analyzer to the side branch of tubing so that calibration gas can be sampled without pressurizing the analyzer.



3. Purge the CAMS-I regulator 3 times to insure removal of all ambient air from the regulator; then dial in a delivery pressure of several psig. Leave gas cylinder turned on but secure flow using the regulator outflow valve.
4. Turn on analyzer by pressing the red key. The LCD will show the company name, model no., and information on key functions.
5. Press the "0" key to exit that screen. The LCD display will show the following choices:
  - 1-General Utilities
  - 2-Read Gas Levels
  - 3-View/Print/Analyze
  - 4-Download Data
6. Press "1" for General Utilities. The display will show the following:
  - 1-Check Time/Date
  - 2-Battery Status
  - 3-Memory
  - 4-Calibration 0-Exit
7. Press "2" to read the available battery capacity. If there is insufficient charge, attach analyzer to charger that is run off 110 volt line current and a) charge for at least 1 hour or b) use while charging.
8. Press "0" twice and then "2" to read gas level. Press "5" to turn on pump. Analyzer is now measuring CO<sub>2</sub>. Allow to warm up for 5 min.
9. Open the CAMS-I regulator valve and adjust gas flow so it is just audible as it exits the tubing.
10. Wait at least 1 min for reading to stabilize. Record reading at top of daily data sheet.
11. Shut off calibration gas flow.
12. Close valve on CAMS-I cylinder and bleed regulator down.
13. Leave analyzer on. Analyzer can now be moved about the sub to measure CO<sub>2</sub>.
14. For each reading, use a separate line on the data sheet. Include any comments on the bottom.
15. When finished turn analyzer off by pressing red key.

16. Subsequent sampling for CO<sub>2</sub> during the same day can be done without repeating calibration check. Simply turn on the instrument by pressing the red key, press "0", then "2", then "5"; allow to warm up 5 min before using.

# **NMRI**

## **CO<sub>2</sub> Sampling Data Sheet**

**(Use New Sheet Each Day)**

CO<sub>2</sub> Unit: Geotech CD500LB Date: \_\_\_\_\_

Time On: \_\_\_\_\_ Submarine: \_\_\_\_\_

Operator: \_\_\_\_\_

CO<sub>2</sub> Concentration in CAMS Gas: \_\_\_\_\_ (%)

Geotech CAMS Gas Reading: \_\_\_\_\_ (%) Time Checked: \_\_\_\_\_  
**(DO FIRST EACH DAY)**

## Notes:

## **APPENDIX C: OPERATING PROCEDURES FOR THE RECOMMENDED ANALYZER, GEOTECHNICAL CDM-1000/LONG.**

Sufficient information is provided here to calibrate and measure CO<sub>2</sub> onboard a submarine. It is assumed that the calibration gases will not be onboard and that the user will have calibrated the unit prior to going onto the submarine. This was the rationale behind the 90-day testing during which the instrument was not recalibrated. Other instrument functions are available which can be accessed via the menu but won't be discussed here.

### ***Batteries/charging***

The CO<sub>2</sub> analyzer is normally run off its self-contained NiCad batteries. However, when the batteries require charging, the analyzer can be used when it is attached to the charger. The charger plugs into 110 volt line current. The instrument must have batteries in place to operate. Ideally, NiCad batteries should be fully discharged and recharged during operation rather than continually topped off without a full discharge. However, this probably will not be possible. An overnight charging should provide 12 h of usage.

### ***Calibration and Use***

1. Calibration should be done at temperatures 18 to 24 °C (65 to 75 °F).
2. Required gases with high-purity (stainless steel diaphragm) regulators to allow adjustment of gas flow down to several liters/min:
  - a. Zero gas = CO<sub>2</sub>-free, hydrocarbon-free air
  - b. Span gas = 7.5% CO<sub>2</sub>, balance hydrocarbon-free air, primary standard certified to  $\pm$  1% relative.
3. Purge both regulators 3 times to insure removal of all ambient air from the regulator; then dial in a delivery pressure of several psig. Leave gas cylinder turned on but secure flow using the regulator outflow valve.
4. On both regulators, install tubing (e.g., Tygon, nylon, Teflon) that contains a tee to allow sampling with the analyzer.
5. Turn on analyzer by pressing the red key. The LCD will show the company name, model no., and information on key functions.

6. Press the "0" key to exit that screen. The LCD display will show the following choices:

- 1-General Utilities
- 2-Read Gas Levels
- 3-View/Print/Analyze
- 4-Download Data

7. Press "1" for General Utilities. The display will show the following:

- 1-Check Time/Date
- 2-Battery Status
- 3-Memory
- 4-Calibration 0-Exit

8. Press "2" to read the available battery capacity. If there is insufficient charge, attach analyzer to charger that is run off 110 volt line current and a) charge for at least 1 hour or b) use while charging.

9. Press "0" to return to the previous screen. Press the "4" key to calibrate. Press "5" to start pump. Allow to warm up for 5 min.

10. Connect the inlet port of the CO<sub>2</sub> analyzer to the side branch of the Span gas tubing so that calibration gas can be sampled without pressurizing the analyzer (in similar fashion as with NMRI testing in Fig. 1 of this report).

11. Open the Span gas regulator valve and adjust gas flow so it is just audible as it exits the tubing.

12. Wait at least 1 min for reading to stabilize. If reading is within 0.20% of the calibration gas (e.g., 7.50 ± 0.20%), calibration is unnecessary, shut off calibration gas flow, and go to step #17.

13. If calibration is necessary, press "1" to calibrate and then enter CO<sub>2</sub> concentration (e.g., 7.50%). To backspace over an entry mistake, press and hold "0".

14. Press "0" to exit screen and then "1" (i.e., "Yes") to calibrate.

15. Observe readout. Meter reading should be within 0.20% of the calibration value. Calibration can be repeated if desired.

16. Shut off Span gas flow.

17. Press "0" twice and then "2" to read gas level. Press "5" to turn on pump. Analyzer is now measuring CO<sub>2</sub>.

18. Remove span gas tubing and attach Zero gas tubing to analyzer.
19. Open the Zero gas regulator valve and adjust gas flow so it is just audible as it exits the tubing.
20. Wait at least 1 min for reading to stabilize. If reading is not within 0.20% of 0, instrument should not be used unless this problem is corrected.
21. Shut off Zero gas flow, close valves on both gas cylinders, and bleed down regulators.
22. Turn analyzer off by pressing the red key and remove Zero gas tubing. Instrument is now calibrated and NMRI testing indicates analyzer should be useable for up to 90 days without recalibration with estimated accuracy  $\pm$  25% relative.
23. Analyzer can now be moved onto the submarine to measure CO<sub>2</sub>. Simply turn on the instrument by pressing the red key, press "0", then "2", then "5"; allow to warm up 5 min before using.